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THE QUANTIFICATION OF THE COMMITMENT

OF MESSAGE CENTERS IN THE ARMY

COMBAT AREA COMMUNICATION SYSTEM

A THESIS

Presented to

The Faculty of the Graduate Division

by

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THE QUANTIFICATION OF THE COMMITMENT

OF MESSAGE CENTERS IN THE ARMY

COMBAT AREA COMMUNICATION SYSTEM

Approved:

Chairman

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SUMMARY

The United States Army has several types of field communication systems, the most extensive of which is the Field Army Area Communication System. It is a network of communication centers dispersed throughout the combat zone which is interconnected electronically by a combination of radio and cable circuits. Within each of the communication centers is a message center through which all written correspondence for electrical transmission is routed.

This research is a statistical analysis of the ability of a message center to process message traffic under varying input conditions. Through the construction of a computerized model and the subsequent analysis of data generated by the model the research was aimed at determining the values of input parameters which caused messages to be delayed excessively. With this information the Army Commander is able to prescribe the organization of a particular message center to prevent unnecessary delays in message handling prior to committing the message center to an area of responsibility in the composite communication plan.

The model was programmed for the IBM 7094 digital computer system utilizing General Purpose System Simulator III (GPSS III), a special purpose programming language. The input to the model consisted of messages arriving in a random manner where the time between arrivals is described by the Gamma density function. By varying the shape parameter

and the mean time between arrivals, a wide variety of inputs were obtained simulating environmental actions under assorted combat conditions. In addition, each message generated is assigned one of four priorities which denotes the order in which it is to be processed, and a classification which denotes the security precautions necessary in handling and transmission. Both the priority mix and the classifications were varied to determine their effect on the operation of the system.

It was found that the cause of excessive delay times was a result of congestion at the facility processing classified messages. To alleviate this congestion additional facilities were added to the model. The results were depicted in a series of tables giving the ranges of the various parameter values for which a particular organization of the message center could process the specified input within an acceptable time limit.

CHAPTER I

INTRODUCTION

Background

The various components of Army activity are connected by some means of communication. Whether it be a sophisticated space-satellite system, a simple "handy-talkie," or merely a runner, there is always some method for communication between units. The need for communication in any military organization is evident. The evolvement of communication systems has been largely based on the needs of the service. The expansion of involvement in world affairs has stimulated a parallel growth in the mission of the armed forces, particularly the Army. The deployment of units to all parts of the world has become common; and,as a result, the role of the communication activity in the Army has developed into one of providing world-wide service to commanders at all levels. This service is provided by the Signal Corps. Fortunately, the advancement of technology has kept pace with increased mission requirements, and this service is not only feasible but in existence today.

Advancing technology has had one adverse affect, however, in that it has produced equipment that is extremely complex. As this complexity increases, so must the skill of the user. As a result, the training and retraining of maintenance and operator personnel has become a costly and time consuming process, and a major concern to both the

Army and the vendor.

Another problem the Army confronts as it acquires such complicated equipment is the additional cost associated with increased reliability, range, versatility, speed, etc. Each of these desirable characteristics is purchased at a price that is a function of the particular characteristic and equipment. The trade-off between price and system effectiveness is dependent on the specifications of the system. The continuing requirement for more communication systems with greater capacity and range has altered specifications to the point that costs have become a definite limiting factor.

It is not the objective of this research to dwell, in any detail, into costs and maintainability but only to present them as motivation to the main thesis. There is no question that the scientists and engineers in the electronics industry have provided the Army with the communications equipment necessary to accomplish its mission. In fact, they have gone beyond these requirements. It is now appropriate to employ a systems approach to study methods for optimally utilizing existing personnel and equipment.

The implication is not being made that operations research and systems analysis approaches have been neglected by the Signal Corps. To the contrary, various organizations within and outside the Army have made studies to evaluate the effectiveness and efficiency of communications at most levels considered to be strategic in nature, i.e., General Staff, Continental United States, Theaters, etc. Most of these studies involve fixed station operation (immobile) and are concerned with automatic systems. Generally, these systems are operated and maintained by highly-trained enlisted personnel and/or civil servants or on a contract basis with a civilian organization. The problem mentioned above, concerning maintenance, is not particularly evident in these installations since only the most qualified technicians are employed.

The other aspect of Army communications is that concerned with tactical and field units. Here the equipment is mobile, weatherproof and shockproof and is generally designed to operate in any part of the world. Operators and maintenance personnel are almost entirely enlisted and have limited training when compared with fixed station attendants.

Concept of Operations

The first tactical unit that is found when descending the Army's organization is the Field Army. It is a composite of tactical and support units and is designed for a particular situation which is largely dependent on the opposing enemy forces and the terrain in which it operates. The concept of communications within the Field Army is based on the grid system, which consists of a number of Communication Centers, dispersed throughout the Army area. These are interconnected by some long-line facility (either cable or radio, or both). Figure 1 shows a typical communication system as it would appear in an Operation Order* for deployment of Signal Corps personnel. The circles denote Communica-

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*"The Operation Order is the formal directive resulting from operational planning (20, p. 70)." It is a detailed order for the conduct of a field exercise or a phase of combat.

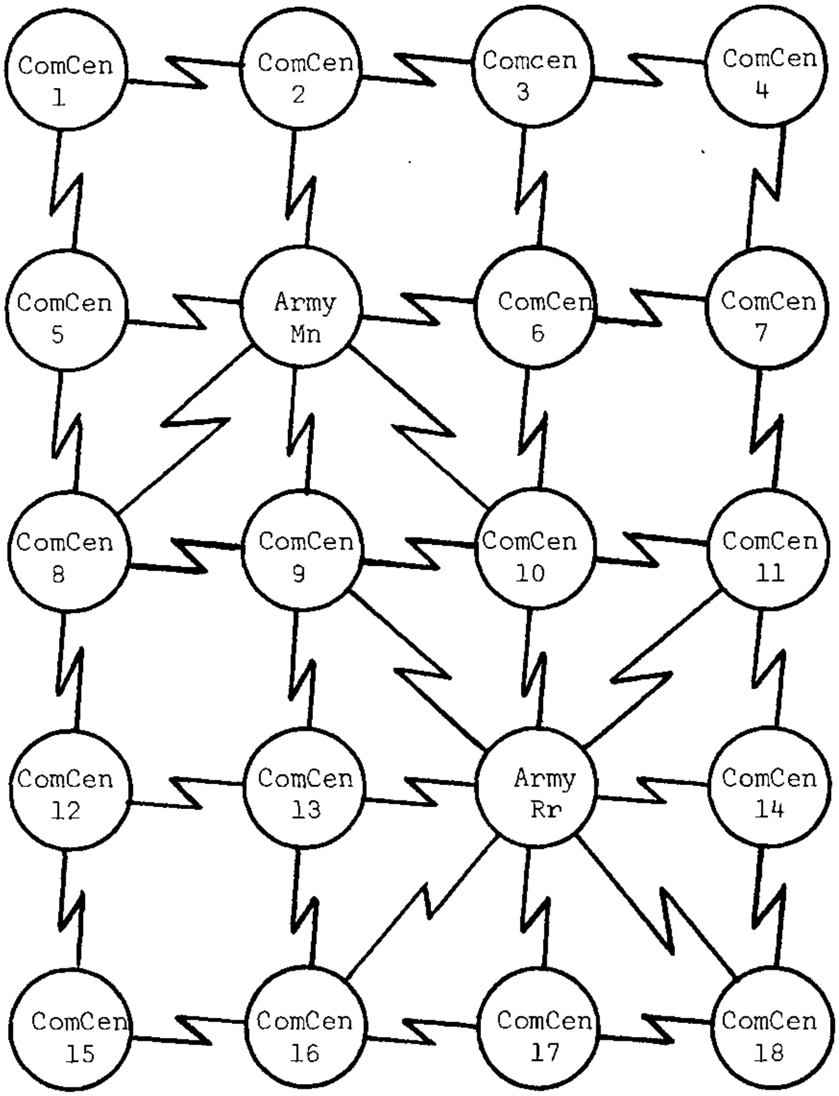

Figure 1. The Army Area Communications System (Grid System)

tion Centers which are joined (electronically) by multi-channel radios. Though this system is typical, it is not necessarily standard. The combination of Communication Centers and radio networks varies considerably with the tactical situation.

The Field Army Signal Officer has under his supervision six batallions with four companies each that are responsible for the installation, operation, and maintenance of the Combat Area Communication System. This is a total of 24 Communication Centers available for use. In addition, many of these units may be augmented with teams from TOE* 11-500D, a special authorization for supplementing specific organizations with additional personnel and equipment for various contingencies.

The concept of operation for the conduct of a particular phase of combat or field exercise is a result of planning at the Army level. The Signal Officer at this level bases his plan on the tactical situation and the communication requirements of the units involved. Generally, the plan is to establish the grid system in sufficient depth and width to encompass the entire Army area. The Communication Centers are ideally placed in areas of high troop concentration so that their facilities can be used to the greatest advantage.

Those units that are not used are maintained in a reserve status for assignment as teams to various locations or for future commitment. The concept of a reserve for communication units is similar to that of

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*Table of Organization and Equipment.

artillery units in that they are retained for a specific mission and not necessarily for emergency conditions. Reserve units can be considered as either units designated for some future plan of action or as a pool of teams to be assigned to areas requiring additional communication support.

It is evident that the Army Signal Officer must make some trade-off between the effectiveness of the reserve units and the requirement for additional operating teams at other locations. It may be necessary in some situations to reassign component parts of reserve units to operational units, thereby rendering the reserve unit inoperable. This decision is based on a trade-off between the expected utilization of the reserve unit and the urgency of the requirement for the team in question. Throughout this thesis it is assumed that the Army Signal Officer has the information available and the ability to make this decision under any given set of circumstances.

In the design of the Combat Area Communication System the Communication Center is considered the basic component. It normally is operated by a company-size unit composed entirely of Signal Corps personnel (21). The organization of the Company is shown in Figure 2.

There are two sections in the Communication Center through which all communications flow. The first is the Wire Operations Section which operates and maintains the switchboard, and the second is the *Message Center Section*. All verbal communications originating in or around the area are channeled through the switchboard for termination by local subscribers or for relay to remote switchboards. The Message

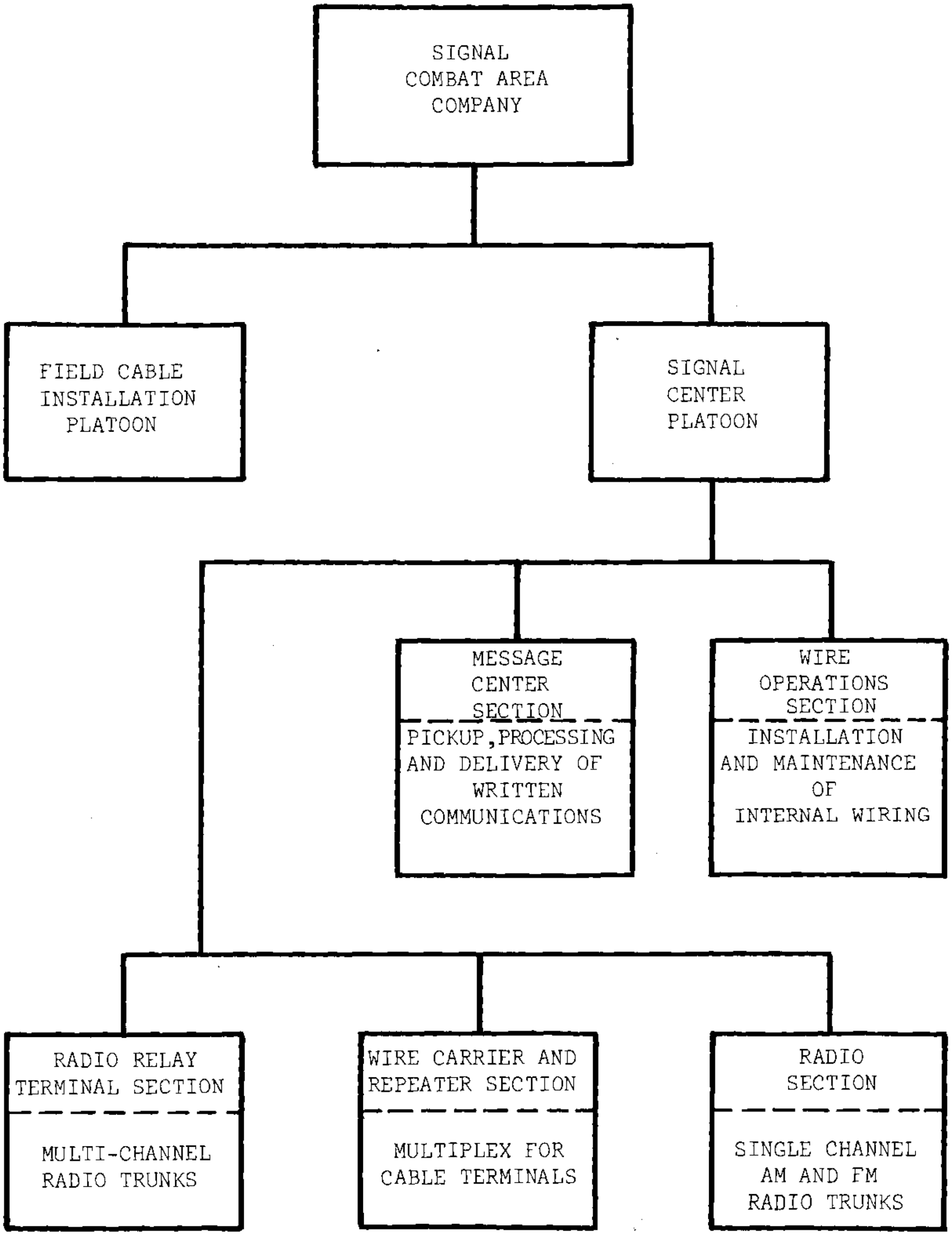

Figure 2. Signal Combat Area Company (TOE 11-87E)

Center Section is responsible for pickup, processing and delivery of all written communications. It is the Message Center Section with which this thesis will be concerned.

A particular problem that the Army Signal Officer has is that of allocating Communication Centers to areas within the combat zone to provide message handling facilities for tactical and logistical units within that area. At present the technique used is based on the personal judgment of the Signal Officer. The decisions are strictly subjective and in many cases inadequate. It is to be shown that these decisions can be made objectively through a statistical analysis of the effects of various inputs on the message center. For instance, given a certain average input with a particular density function for time between arrivals, what will be the requirements in terms of personnel and equipment to properly handle these messages? Will it require an augmented platoon from one of the TOE 11-500D teams, one with reduced strength, or perhaps an entire company committed from the pool of reserve units? In addition, what will be the effect of the expected mix of precedences* and classifications** on the output?

The objective of this thesis is to answer these questions through the construction and evaluation of a computer simulation of a

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*Precedence is the term which the Army gives to a message to denote the relative order of handling and the order in which the subject matter is to be noted. The various precedences are discussed on page 13.

**The term classification denotes the importance of the contents of the message to the security of the nation.

typical Field Army message center. The model is designed to simulate the processing of messages from the time they arrive at the message center until they are transmitted to some remote location. The processing procedure used is standard throughout the Army and is established by regulations from which no deviation is allowed. The environment in which the message center operates provides the input of messages. This input is entirely dependent on the tactical situation and the number and type of units which the Communication Center is supporting. This information is available to the Army Signal Officer in the form of afteraction reports from numerous field exercises. The effect of input characteristics on the message center operation is not available, however, and must be derived prior to committing a Communication Center to support a specific area. The primary problem the Signal Officer faces is that there are many environmental parameters to be simultaneously considered. Not only is the rate of arrival of messages to the message center a random variable, but the mix of precedences, the percentage of classified messages, the service times at the various processing points, the length of the messages, and the destinations for which the messages are designated are also variable. The variation of any one of these parameters has some effect on the output. For this project it was not considered feasible to vary all these parameters but rather to select specific values for a few and then determine the effects of varying the others. In this respect, the scope of the study is somewhat limited.

Scope

The fact that this research is directed at the Field Army Signal Officer does not necessarily limit its use to that office. Any agency concerned with the engineering and development of field communication systems should find the results useful. For example, consider the Communication Officer at a single field message center. The movement of units into and out of his zone of responsibility is a frequent occurrence in most training exercises and combat situations. If he has some notion of the number and type of units that are moving, which in turn will provide him information about the increased input characteristics, he will be able to plan for the expected utilization of his facility.

This research is limited to field communications, and it is not applicable to fixed station operations. With considerably more research and a general reprogramming of the model, this approach could be undertaken for fixed station facilities; however, the usefulness of such a project would be in question, since supported units are relatively stationary and inputs are less variable.

Environment

The first step in the solution of the problem is the definition of the system and its environment. The real world system under consideration is the Field Army Combat Area Message Center. The environment consists of those units for which the message center provides service, i.e., the tactical and logistical units which originate written correspondence, and the tactical and logistical units which are denoted as the addressee for this correspondence. The input to the message center consists of messages arriving in some random manner described by a particular density function. These messages arrive by one of three means:

1. Direct teletype from the originating organization addressed to some remote unit.

2. Unscheduled messenger service from the originator for transmission to a distance addressee.

3. Hand carried by the originator for transmission to a distant addressee.

The method of delivery has no effect on the message flow. It is mentioned here only to indicate random arrival possibilities and the likelihood that the mean rate of arrivals is not dependent on time in a combat situation. Regardless of the delivery means, the messages will be received at the message center for the first step in processing for delivery.

In most cases the message will be written on a preprinted form (Figure 3) and in all cases will consist of three parts:

1. Heading: contains the information necessary for preparation and transmission, i.e., originator, addressee, precedence, classification, type of message, etc.

2. Text: contains the information that the originator is giving the addressee.

3. Ending: reserved for message center personnel for proper identification of the message, and the originator.

As each message arrives in the message center, a designated

JOINT MESSAGEFORM

RESERVED FOR COMMUNICATION CENTER

SECURITY CLASSIFICATION

TYPE MSG	BOOK	MULTI	SINGLE

PRECEDENCE

ACTION

INFO

DTG

FROM:

TO:

SPECIAL INSTRUCTIONS

DATE	TIME
MONTH	YEAR
PAGE NO.	NO. OF PAGES

DRAFTER: TYPED NAME AND TITLE | PHONE

RELEASER: SIGNATURE | TYPED (or stamped) NAME AND TITLE

SECURITY CLASSIFICATION | REGRADING INSTRUCTIONS

DD FORM 1 NOV 63 173

REPLACES EDITION OF 1 MAY 58 WHICH WILL BE USED.

Figure 3. Joint Messageform

supervisor checks it to insure proper procedure has been followed and to note the order in which the message is to be handled (see Figure 4). The order of handling is called the precedence of the message. It is assigned by the originator to denote the relative urgency of the information in the text. The four precedences, in order of importance, are:

1. Flash: to be handled as fast as humanly possible, interrupting the processing of any lower precedence message.

2. Immediate: to be processed ahead of messages with a lower precedence, interrupting when appropriate.

3. Priority: to be processed ahead of routine messages, interrupting when appropriate.

4. Routine: to be processed in the order received and after higher precedences.

After the supervisor has checked the messages they are given to a clerk who transcribes identifying information into the Message Center Log. The clerk further segregates the messages according to classification. Each message is designated, by the originator, as being either classified or unclassified. If the message is classified, it means that the information contained in the text is vital to the security of the nation and its compromise by unauthorized persons could be detrimental to the security of the nation. Classified messages are, therefore, afforded special handling, in that they must be given proper physical protection as well as transmission protection. Physical security is provided by armed guard or appropriate containers. Transmission security is provided by the cryptographic unit. This unit encodes the

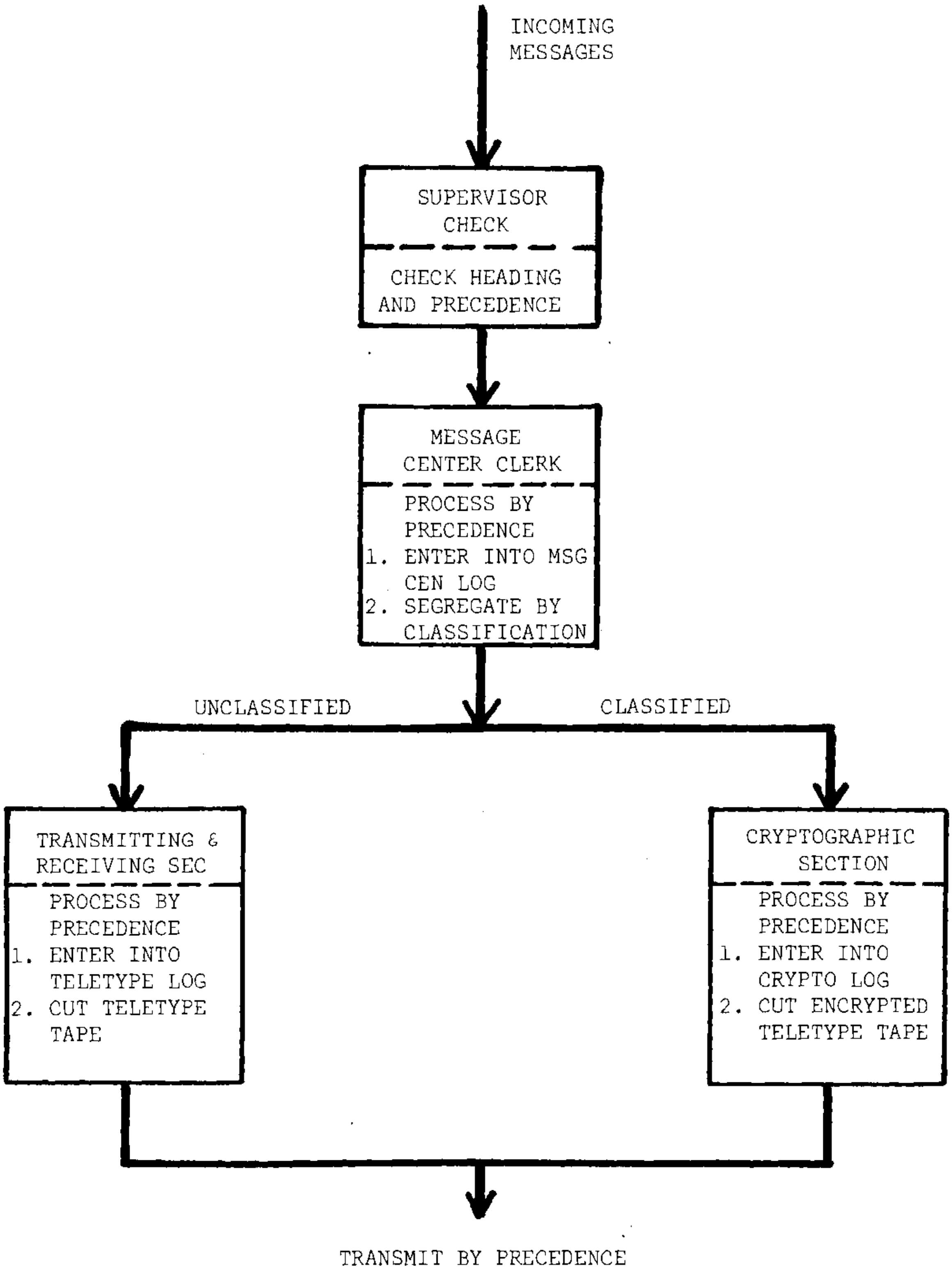

Figure 4. Message Flow

message in such a way that its interception cannot divulge useful information to the enemy. The encoding process is coupled with a device that "cuts" a teletype tape with the characters of the coded language. This tape, when completed by the cryptographic unit, is virtually useless to any agency which does not have a decoding device corresponding to the device on which it was encoded. The tape can, therefore, be transmitted without fear of compromise.

For transmission the tape is sent to the transmitting and receiving unit where it waits until a transmitter is free or until all messages of a higher precedence have been sent. When these conditions have been met, the teletype operator places the prepared tape into a transmitter and informs the distant station that he has a message for them. When the distant station is ready and has been properly identified, the operator activates the transmitter and monitors the transmission until it has been properly transmitted and acknowledged. When the receiving station has acknowledged receipt, the sending station is relieved of further responsibility for the message.

Unclassified messages are handled in the same manner as classified with the exception that they are given directly to the transmitting and receiving section after they have been logged by the message center clerk. A teletype operator then "cuts" the tape (which will be in clear text) and transmits it to the desired destination.

Prior to each servicing facility in the message center,there is some sort of queue that each message enters before being processed. It may be an "in box" on a clerk's desk, or a safe (for classified messages), or a nail on a tent pole (for teletype tapes). Regardless of the physical representation, the message enters a waiting line. If the message is of a higher precedence than the other messages in the waiting line or in the service facility, it will exert preemptive rights, interrupt service and be processed ahead of the other messages. This is standard procedure for each waiting line and service facility within the message center.

This brief description of the operation of a typical Field Army Message Center is to serve as a foundation on which to build a model to represent the real world system.

Approach

In selecting a technique for modeling the system, a likely choice involves some applications of queueing theory, since the operation of the message center involves waiting lines and service facilities. A little research into the present uses and the "state of the art," however, indicates that the construction of such an analytical model is not possible for this system, as will be evident as the experiment is described. Further research indicates that an acceptable technique for modeling complex systems where analytical solutions are impossible or are not economically feasible, is simulation using Monte Carlo methods.

Once simulation was selected, the researcher was faced with two problems:

1. Since the simulation requires an enormous number of arithmetical calculations, a digital computer is a necessity.

2. The programming involved in a simulation of this type using a general purpose language is a tedious and time-consuming process.

The first problem was solved by the University of Georgia which offered the use of its IBM 7094 computer; the second by the use of a special programming language developed by the IBM Corporation entitled "General Purpose System Simulator III (GPSS III)" (25).*

With the decision made to use simulation and with the resolution of the two problems above, the method of approach can be broken down into two phases:

1. Construction and validation of the model.

2. Manipulation of the model to evaluate system operation under various sets of conditions (parameter values).

Assumptions

To give credence to this approach, certain assumptions must be made about the real world system. Though these assumptions may dilute the conclusions, they are necessary to maintain feasibility in the modeling process.

1. The times between arrivals of messages at the message center are independent random variables which can be approximated by a statistical distribution.

2. Service times for the various stations within the message center are independent random variables which can be approximated by a

---

*The Burroughs digital computer system at Georgia Tech does not have a GPSS III capability. GPSS III was programmed by IBM for IBM machines; therefore, the University of Georgia was asked for assistance.

statistical distribution.

3. The calling population is infinite.

4. All queues have the capacity of containing an infinite number of messages.

5. The arrival of messages is independent of time.

6. All teletypewriter systems are full-duplex.*

With these assumptions made, the construction of a computer simulation and the subsequent evaluation of the data becomes feasible. The objective of this research is to determine ranges for the values of the various input parameters which cause the model to behave in an undesirable manner. Once these values are known, the model can be manipulated to compensate for their effects.

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*A full-duplex teletypewriter system is one that is capable of transmitting or receiving messages simultaneously.

CHAPTER II

LITERATURE

Army Communications

The history of communications in the United States Army is long and not of particular importance to this thesis. The development of the concept of present-day systems is of importance, however, because it was a direct result of changes in the conduct of warfare.

> Today the commander must direct amphibious landing, coordinate air-delivery of men and supplies, control close air support, call in artillery fires, or order the final assault on his unit's objective, to name a few modern requirements for rapid and far-reaching communication.
>
> As late as World War I only limited use was made of electrical communications pioneered during the Civil War. However, the technical improvements in electronic equipment and communications that occurred between the World Wars greatly accelerated the use of signal communications in the Army, and, in fact, made possible the control and coordination of the massive combined assaults on Hitler's Europe, for example. But there is still a need for improved communications equipment.
>
> The burst of the first atomic bomb over Hiroshima in 1945 foretold the need for better communication equipment in the Army. As the years passed and techniques were developed to fit the requirements of the tactical atomic weapons in the Army, it became evident that smaller, lighter, more rugged, and more powerful means of communication were needed to meet the needs of today's atomic-capable forces. The dispersal of manpower and materiel, coupled with increased mobility and firepower, demand more and better means of communications. (18, p. 6)

> As early as World War II . . . it was found that the signal troops organic to a Field Army were not sufficient to provide

> the administrative communications necessary for service support elements*. . . . To provide this, additional communication teams were obtained from the communication zone** and from Theatre,*** organized loosely into a Signal Service Battalion, and then dispatched to the many points where signal support was required. (39, p. 6)

Together with advanced equipment and the organization of signal units into teams which were deployed throughout the army area, a new concept in military communications was born, the Army Area Communication System.

The system did not achieve its current configuration (Figure 1), however, until the end of the Korean War when it was realized that an even greater demand for communication was in evidence than ever before. As a result, the Area Communication System was expanded to include not only support units but also combat units.

> The system extends from the rear of the field army area through the combat zone and connects into the division communications system. Thus, the field army communication system will transcend command boundaries. The army signal centers are not associated with any particular unit of command post, but rather, provide support to all troops located in the area. They are positioned in the army area as required by local geography, ground lines of communication, and troop population density. (23, p. 25)

The importance that the Army attaches to the Area Communication System is evidenced by a paragraph from the Staff Officers Field Manual, one of the most widely used references in the Army:

---

*Those units under the Army Commander that are not directly confronted with the enemy.

**The area directly to the rear of the combat zone.

***The headquarters in command of one or more Field Armies.

> A reliable and versatile communication system is mandatory to the accomplishment of a commander's mission. With such a communication system he is able to use properly his staff agencies and control his combat and supporting forces. The reliability of the modern battlefield communication system is enhanced by the use of the area communication system. . . . Once a versatile and reliable area communication system is in operation, the manifold benefits to a commander and his staff come into full play. They use all available and appropriate communication means to coordinate and control the actions of the command including direct voice contact, written communications, radio, telephone, teletypewriter, and television. (20, p. 76)

The basic component of the Area Communication System is the Signal Combat Area Company which has the mission: "To install, operate, and maintain one area signal center of the army area signal system." (17, p. 18.) The personnel and equipment authorizations are found in TOE 11-87E dated 27 April 1961. This document also contains the organization of the unit (Figure 2) on which much of the discussion in Chapter I was based.

The operation of the Signal Combat Area Company is governed by several different manuals. Of particular interest here are those which establish procedures for the operation of the message center. FM 24-17, *Tactical Communications Center Operations*, dated 14 September 1961, outlines the procedure in detail for a message center somewhat larger than the one under consideration, however:

> This manual is a guide for personnel concerned with the operation of tactical communications centers at all levels of command. . . . This manual presents general practices and methods for planning, organizing, and operating tactical communications centers and message centers. (22, p. 4)

In addition, this manual references other procedures and instructions which are more specific in nature and pertain only to a particular message center, company or command. These are listed below:

> 1. Standing Operating Procedures. An SOP is a set of instructions covering those features of operations that lend themselves to a definite standardized procedure. . . . Each message center has its own SOP to prescribe the details of every operation that takes place in connection with the receipt, transmission, and delivery of messages.
>
> 2. Standing Signal Instructions. The SSI contains communications, operating procedures and general instructions and directives that are relatively permanent in nature. . . . The message center must have a complete copy of the SSI for ready reference.
>
> 3. Signal Operating Instructions. The SOI is an order or series of instructions issued for technical control and coordination of all signal communication agencies throughout the command. It contains operational data and instructions that are subject to periodic or frequent change. . . . The message center must have a copy of the current SOI. (22, p. 9)

These three sets of instructions are normally all that are required for the proper administration of the message center. There are others of a more general nature, but they are not required for day-to-day operation.

The preparation of the message, the responsibility of the originator, is prescribed in AR 105-31, *Message Preparation,* dated 19 August 1965. This Army Regulation specifies in detail the manner in which DD Form 173, Joint Messageform (Figure 3), is to be filled out and emphasizes the importance of assigning the correct precedence and classification.

> The assignment of precedence to a message is the responsibility of the originator, based on a determination of the urgency of the subject matter and the time factors involved. Precedence categories are used to indicate the relative order in which one message is processed in respect to all other messages. A message will not be assigned a precedence higher than necessary to insure that it reaches all addressees in time for accomplishment of the action intended. . . .

Precedence categories indicate to--

1. The originator--the required speed of delivery to the addressee.
2. Communications and staff message control personnel--the relative order of processing and delivery.
3. The addressee--the relative order in which he should note the message; however, precedences have no direct effect on the time that a reply must be sent.

Appropriate use of the various precedence categories is determined by careful consideration of the following:

1. FLASH. The precedence reserved for initial enemy contact messages or operational combat messages of extreme urgency. Brevity is mandatory.

2. IMMEDIATE. The precedence reserved for messages relating to situations which gravely affect the security of national/allied forces or populace, and which require immediate delivery to the addressee(s).

3. PRIORITY. The precedence reserved for messages which require expeditious action by the addressee(s) and/or furnish essential information for the conduct of operations in progress when ROUTINE will not suffice.

4. ROUTINE. The precedence to be used for all types of messages which justify transmission by rapid means unless of sufficient urgency to require a higher precedence.

The originator is responsible for determining the proper security classification for each message in accordance with AR 380-5. Classification should be based upon the contents of the message text and not necessarily with regard to the relationship of the text to other classified material. For example, a reply to a classified message need not be classified provided the text of the reply itself is unclassified. Over-classification imposes unnecessary burdens on administrative and communications elements by requiring additional protective handling, while underclassification may risk disclosure of security information. The originator must, therefore, select the lowest classification which is consistent with the security protection required. (19, p. 4-2)

The Area Communication System is not the only tactical communication facility within the Field Army. Each Corps, Division, Brigade, etc., have their own internal systems for command and control. The area system augments these other systems by joining them to a composite network that is extremely reliable and flexible. In addition, the area system provides a means of integrating separate units* into the Army scheme of operations. Each Communication Center can therefore have as its "customers" two types of units: combat (Armor, Infantry, Artillery), or combat support (Ordnance, Medical, Quartermaster, etc.).

Simulation

The term simulation has had many meanings in the past. Each scientist who has had some influence on its development has applied his own definition, and the result is a class of vague, often conflicting, ideas about just what simulation is and what it encompasses. C. W. Churchman gives two, somewhat philosophical, definitions by saying that:

> The term simulation poses two quite familiar philosophical problems. First, it bears a resemblance to such terms as "existence," "matter," and "mind" in that it is not only difficult to say what things belong to it, but it is also difficult to say what things do not belong to it. Everything there is can be though of as a simulation of something. Second, the term simulation raises the old familiar question of the meaning of reality because "to simulate" seems to mean "to represent the real by a model." (8, p. 12)

And then a more precise definition:

> x simulates y is true if and only if (a) x and y are formal systems, (b) y is taken to be the real system, (c) x is taken to be an approximation to the real system, and (d) the rules of validity in x are non-error-free. (8, p. 12)

The idea of model building is amplified by Dmitris N. Chorafas:

---

*Those units not assigned to a Corps, Division, etc.

> Simulation involves the construction of a working mathematical or physical model presenting similarity of properties of relationships with the natural or technological system under study. (7, p. 9)

And further by Martin Shubik:

> A simulation of a system or an organism is the operation of a model or simulator which is a representation of the system or organism. The model is amenable to manipulations which would be impossible, too expensive or impractical to perform on the entity it portrays. The operation of the model can be studied and, from it, properties concerning the behavior of the actual system or its subsystems can be inferred. (36, p. 199)

Though more restrictive Thomas H. Naylor gives a definition that gives creditability to the use of the term in this thesis:

> Simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behavior of a business or economic system (or some component thereof) over extended periods of real time. (32, p. 3)

One of the numerical techniques that is used for conducting experiments with simulation models is "Monte Carlo analysis"

> The Monte Carlo method was perhaps first conceived by Von Neuman and Ulan as a method for inverting the procedure classically used in the solution of mathematical problems, and obtaining approximate solutions to the same by simulation, using a probabilistic model and random sampling. (33, p. 106)

Monte Carlo sampling is a method of providing stochastic inputs to the model. The values are generated by a relation

$$X = F^{-1}(RN) \tag{1}$$

where F is the distribution function of X. A series of random numbers which are distributed uniformly between zero and one ($0 \leq RN \leq 1$) with $E(RN) = 0.5$, $V(RN) = 1/12$ serve as input to (1). These numbers can be obtained from a table or they can be generated by a computer using any number of methods. If a digital computer is used, the numbers are usually called pseudo-random numbers and they behave in a manner similar to random numbers in that they are approximately uniformly distributed and hopefully independent with a mean of 0.5 and a variance of 1/12. The closeness of the approximation will depend on the particular method the programmer uses. The congruential-multiplicative method or power-residue method is probably utilized more than any other.

> The results obtained from the application of the Monte Carlo simulation are approximations with the accuracy inversely proportional to the square root of the number of simulation replications employed. . . . (33, p. 107)

Hence, the number of samples taken will be a factor in achieving the accuracy desired.

> The practitioner must decide whether it is advisable to use an electronic computer in any particular situation, and there no doubt will be some cases where the use of hand computations and a statistical clerk will evidently be cheaper than the development of a computer program. (33, p. 107)

For this research a computer was available, and, since the computation time by hand appeared to be excessive, it was decided to program the problem for machine solution. The programming time, even with a general purpose language, could not compare with the time required to solve even a very small portion of the experiments planned if they were done by hand.

The selection of a computer language for programming the simulation was dependent on the capabilities of available hardware. Several special purpose computer languages have been developed which make simulation programming easier and more comprehensive. Two of the most notable of these are: SIMSCRIPT, a product of the Rand Corporation, and General Purpose Systems Simulator (GPSS III), developed by IBM Corporation. A number of other languages have been written but they are primarily for particular types of problems and do not have the general applicability of SIMSCRIPT and GPSS III.

> GPSS and SIMSCRIPT facilitate the preparation of simulation programs in two ways:
>
> 1. They provide a convenient set of concepts for translating the model from an ordinary word description to a more rigorous and complete description from which it is easier to write a computer program. This set of concepts is termed the "world view" of the language.
>
> 2. They provide a language which is particularly suited for transforming the above description of the model into a computer program.
>
> Both languages are predicated on the assumption that computer time is inexpensive relative to the cost of a programmer. As such, they substantially reduce the programming effort required by shifting much of the translating task to the computer. (14, p. 3)

Both languages offer the advantage of shorter programming times when compared to a general purpose language such as Fortran or Algol. Although SIMSCRIPT was written for IBM machines, the systems tape is not a part of the program packages which accompany IBM computers. GPSS III, on the other hand, is available to organizations who own or rent IBM machines as a service of the Corporation. For this reason, GPSS III was chosen for the language in which to model the system.

The GPSS III programmer requires only two reference manuals:

1. General Purpose System Simulator III, Introduction:

The purpose of this manual is to provide an introduction to

> the use of General Purpose Systems Simulator III. It is written for those individuals who have not had previous simulation experience. (25, p. ii)

> 2. General Purpose System Simulator III, User's Manual:

> This manual gives a detailed explanation of the operation of simulation models written with the General Purpose Systems Simulator III. . . .

> It is assumed that the reader is thoroughly familiar with General Purpose Systems Simulator III--Introduction. This manual and the "Introduction" complement each other. The introduction enables the new user of GPSS III to develop a broad range of models. Inevitably, however, the GPSS III user will encounter complex models which require a more detailed understanding of the GPSS III program. This manual should resolve the numerous and, often times, fascinating subleties which arise in GPSS III simulation models. (26, p. 1)

The details of how GPSS III was used in the model building process will be covered in the following chapter. The programming time was considerably less than it would have been if a general purpose language such as Fortran or Algol were used.

Army Communications and Simulation

If we speak of communications in general and consider simulation as representing the real by a model, the literature is abundant. Since 1905, when Mr. A. K. Erlang, an engineer with the Copenhagen telephone exchange, used the principles underlying queueing theory to study the effects of fluctuations of incoming calls on a switchboard (31, p. 2), to the present day uses of operation research techniques on complicated communication systems and networks, the uses of simulation have been many and varied. Recently, however, the term simulation has come to mean a "technique for conducting experiments on a digital computer" (32, p. 3). The majority of the work in modeling communication problems has used the term in this sense (1, 3, 4, 6, 9, 11, 16, 27, 29, 34, 35, 37). Other modeling techniques have been used to a limited extent; notable are linear and dynamic programming and gaming and queueing techniques (5, 10, 12, 13, 15, 30, 38, 41). Generally, simulation is chosen over other techniques because of its applicability to model a system, in its entirety, in a time-variant environment.

The use of simulation in the study of Army communications systems is difficult to substantiate since there is very little literature available on the subject. This does not imply that no work has been done in this area, only that the results have not been made available for public use. In an attempt to determine the extent of research in this area three studies were requested from the originating agency (5, 11, 42) and in each case the request was denied.

The Signal Corps conducted a study in May, 1963, to determine the effects of communications on a tactical situation, and the effects of the tactical situation on various communication systems.

> The Signal Corps Ground Combat Simulator is a fully computerized, dynamic, two sided, free running model of ground combat between two forces up to division in size. It is a research tool which: 1. permits the detailed observation of communications events in a combat environment, and 2. provides a means of measuring, in terms of combat outcomes, the relative merit of competing communications systems concepts. Tactical actions of two divisions in conflict are determined by input data which specify the TOE, organization for combat, SOP, tactical and other doctrine, mission, terrain, environment, and the signal system. Any of these may be changed at will to study the ability of the communication system under analysis to support a wide range of tactical action. (6)

The significance of this study is the realization by the Signal Corps of the ability of simulation to replace costly field exercises or combat as a method of evaluating communications systems. Heretofore, all but minor changes in procedures and systems have been the result of experiences or trials in field maneuvers or combat situations.

CHAPTER III

PROCEDURE

Introduction

The procedure used in performing this research was subdivided into two separate phases. The first phase is the translation of the real world system into a representative model with the subsequent validation of that model to determine how nearly it simulates the real system. The second phase involves experimentation with the basic model to test its reaction to different environments;* and like the first there will be generation of data and statistics necessary for evaluation.

Construction and Validation of the Model: Phase I

The translation of the system described in Chapter I and depicted in Figure 4 into a general purpose computer model employing GPSS III is a straightforward procedure, and this was accomplished in two steps:

The Flow Diagram

Each waiting line, service facility, and routing procedure within the message center is clearly defined by appropriate Army Regulations. The number and type of waiting lines and service facili-

---

*The environment provides the input to the system. In Phase II the values of the parameters which make up the input will be varied.

ties are given in a Table of Organization and Equipment (21), and the procedure to be used in processing the various types of messages is described in detail in FM 27-17 (22). The construction of a GPSS III flow diagram is then a matter of matching the components and routing procedures of the message center with an appropriate symbol to represent that activity or procedure. The flow chart developed for this system is contained in Figure 5.* Each entity within the diagram is denoted by a block** number (beneath the symbol) and a brief explanation of the block's mission in the model.

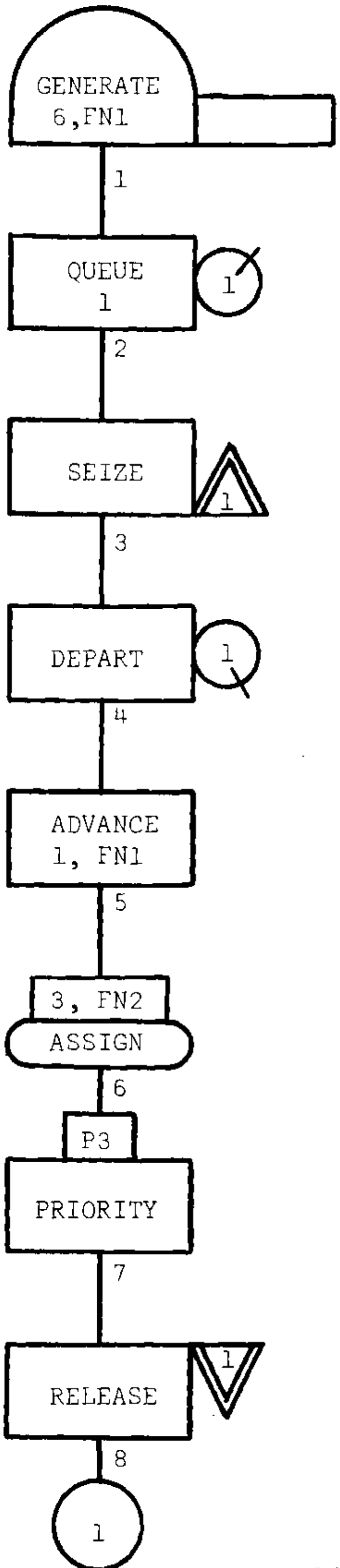
Although most of the symbols are self-explanatory, a brief discussion of their function in the model is warranted. The first block, entitled GENERATE, creates messages to be processed by the message center. In the first phase of the study the assumption was made that the interarrival times have an exponential distribution. The distribution function of the exponential distribution is FN1 in the GENERATE block. FN1 is a reference to FUNCTION 1, a definitive entry,*** which is a set of 24 ordered pairs (F(t),t) of numbers. Each pair of these numbers denotes a point on the curve of the exponential distribution function (see Figure 6),

---

*Figure 5 begins on page 33 and ends on page 41.

**A block is defined as a separate entity in the GPSS III program.

***Describes or defines an activity or action within the program. Definitive entries are not assigned block numbers and are not considered a part of the operational section of the program. Other definitive entries, which will be mentioned later in this chapter are TABLE and VARIABLE statements.



Create incoming messages with interarrival times distributed by FUNCTION 1 and a mean of 6 min.

Wait until SERVICE 1 (Supervisor Check) is free.

Take possession of SERVICE 1.

Leave QUEUE 1.

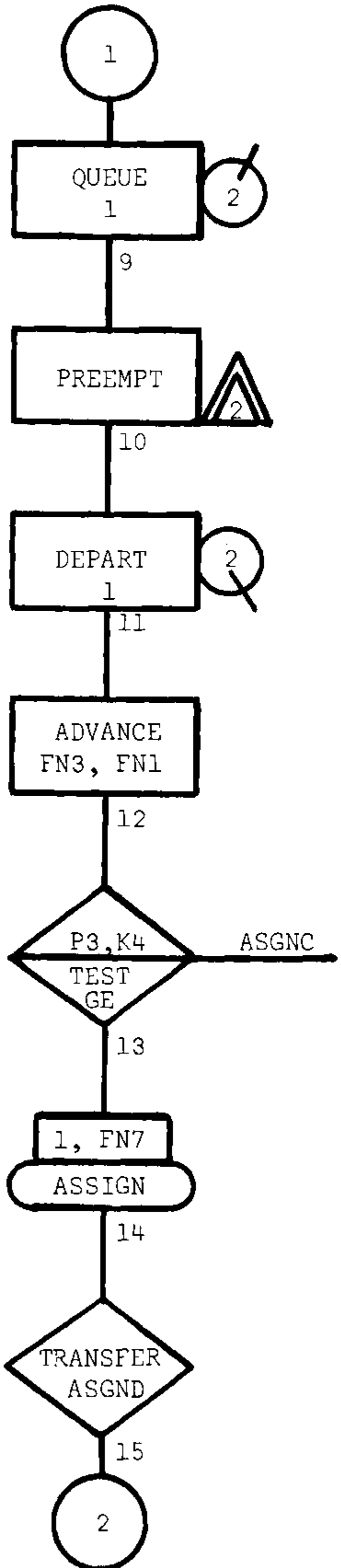
SERVICE 1. Service times distributed by FUNCTION 1 with a mean of 1 min.

Assign precedences to parameter 3, distributed according to FUNCTION 2.

Give precedences priority status according to Parameter 3.

Leave SERVICE 1.

Figure 5. GPSS III Flow Diagram



Wait until SERVICE 2 (Message Center Clerk) is free.

Interrupt lower precedence messages in SERVICE 2 according to priority status.

Leave QUEUE 2.

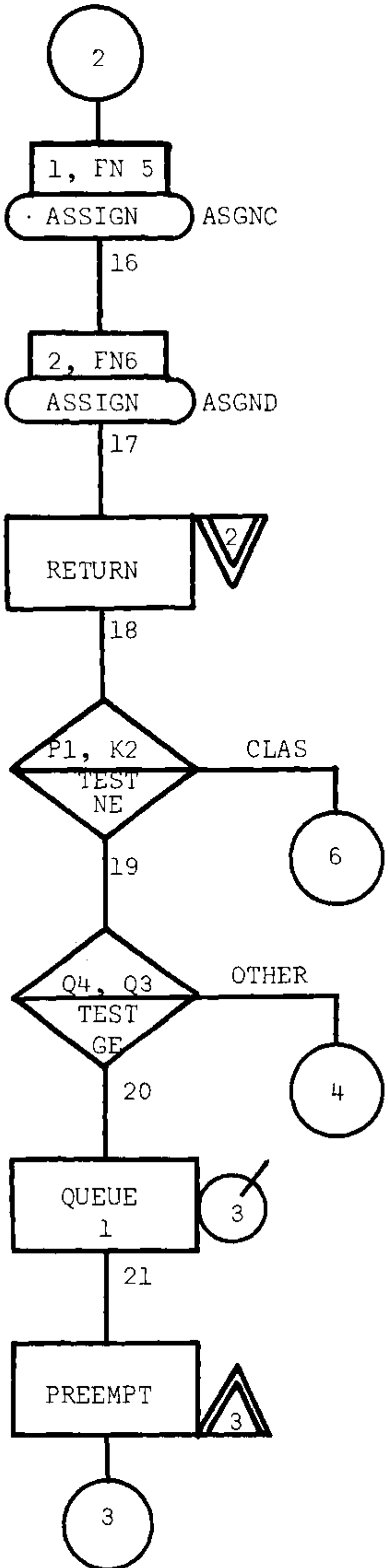
SERVICE 2. Service times distributed by FUNCTION 1 with a mean designated by FUNCTION 3.

If Priority status is less than 4, send to ASGNC; if not, send to next block.

Assign security classification, to messages with Priority 4, according to FUNCTION 7.

Send messages with Priority 4 to ASGND.

Figure 5. GPSS III Flow Diagram (Continued)



Assign Security classification, to messages with priority 1, 2, and 3, according to FUNCTION 5.

Assign destination to parameter 2 according to FUNCTION 6.

Leave SERVICE 2.

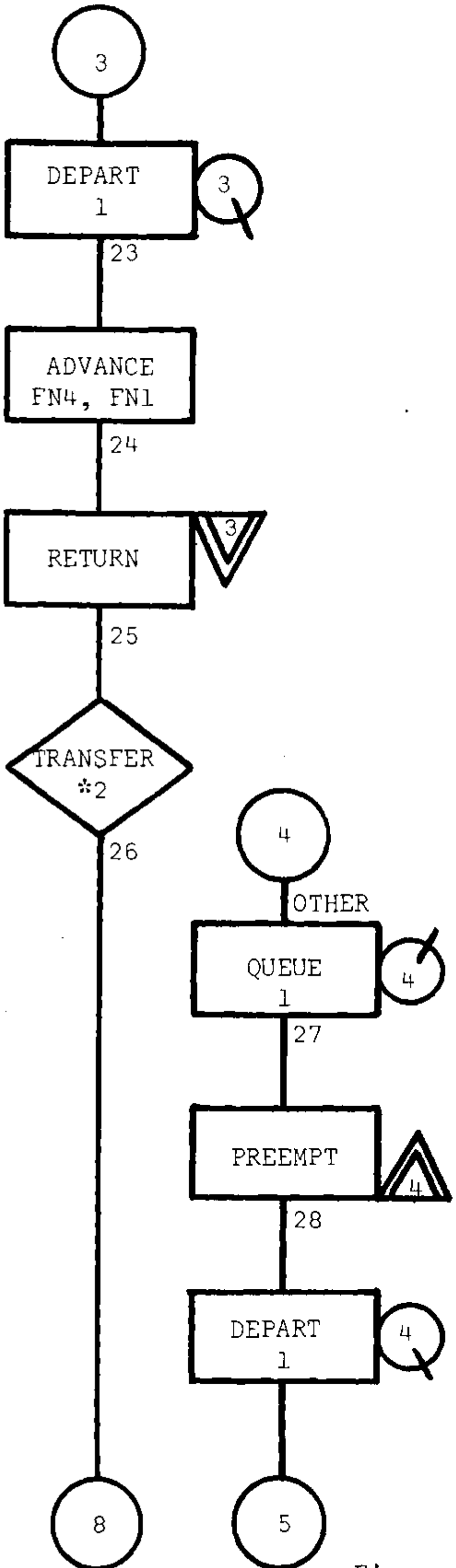
If message is classified, send to CLAS; if not, send to next block.

If QUEUE 4 less than QUEUE 3, send message to OTHER; if not, send to next block.

Wait until SERVICE 3 (unclassified tape cutter) is free.

Interrupt lower precedence messages in SERVICE 3 according to priority status.

Figure 5. GPSS III Flow Diagram (Continued)



Leave QUEUE 3.

SERVICE 3. Service times distributed by FUNCTION 1 with a mean described by FUNCTION 4.

Leave SERVICE 3.

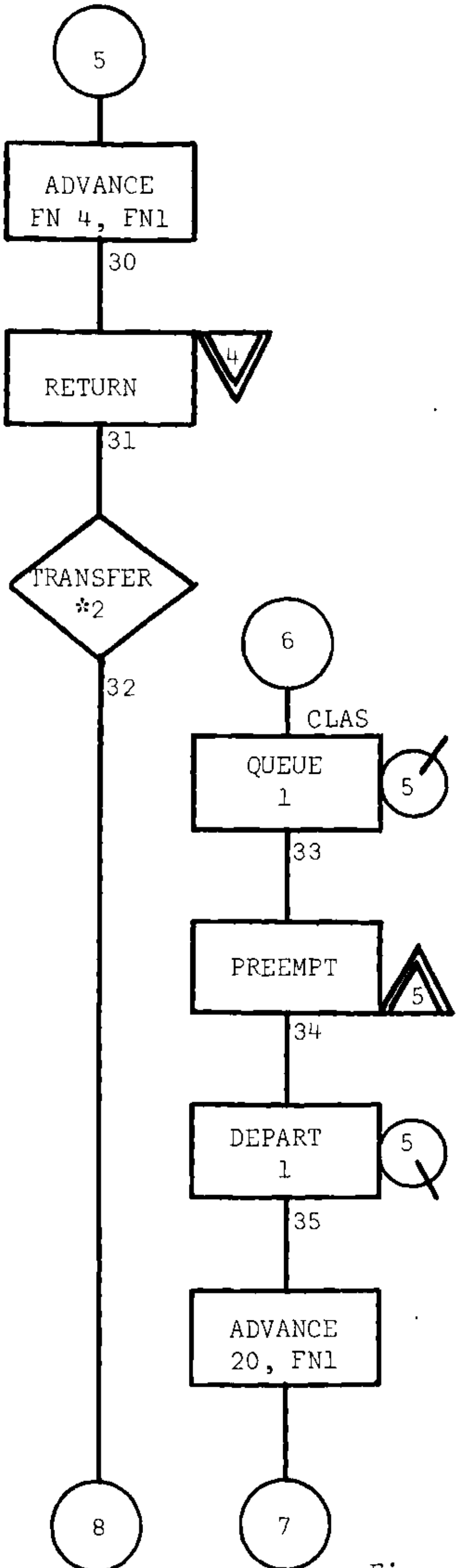
Send to transmitting point designated by Parameter 2.

Wait until SERVICE 4 (unclassified tape cutter) is free.

Interrupt lower precedence messages in SERVICE 4 according to priority status.

Leave QUEUE 4.

Figure 5. GPSS III Flow Diagram (Continued)



SERVICE 4. Service times distributed by FUNCTION 1 with a mean described by FUNCTION 4.

Leave SERVICE 4.

Send to transmitting point designated by Parameter 2.

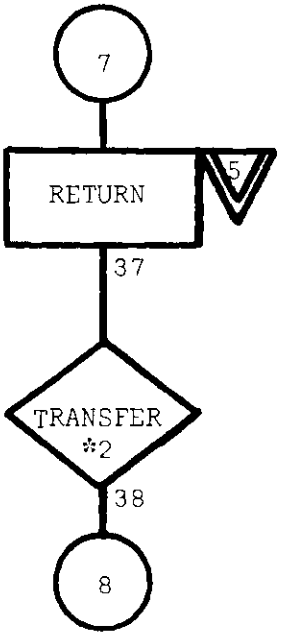
Wait until SERVICE 5 (classified tape cutter) is free.

Interrupt lower precedence messages in SERVICE 5 according to priority status.

Leave QUEUE 5.

SERVICE 5. Service times distributed by FUNCTION 1 with a mean of 20 min.

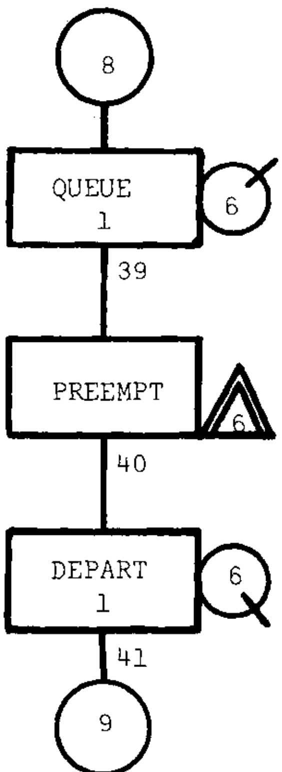
Figure 5. GPSS III Flow Diagram (Continued)



Leave SERVICE 5.

Send to transmitting point designated by Parameter 2.

NOTE: The following is a transmitting point. There are three in the model, each identical to the one described below.

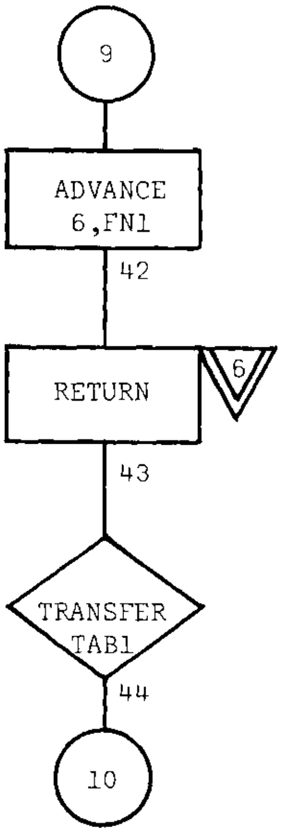


Wait until SERVICE 6 (transmitting point) is free.

Interrupt lower precedence messages in SERVICE 6 according to priority status.

Leave QUEUE 5.

Figure 5. GPSS III Flow Diagram (Continued)

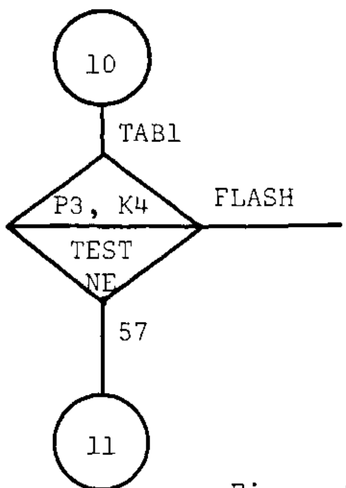


SERVICE 6. Service times distributed by FUNCTION 1 with a mean of 6 min.

Leave SERVICE 6.

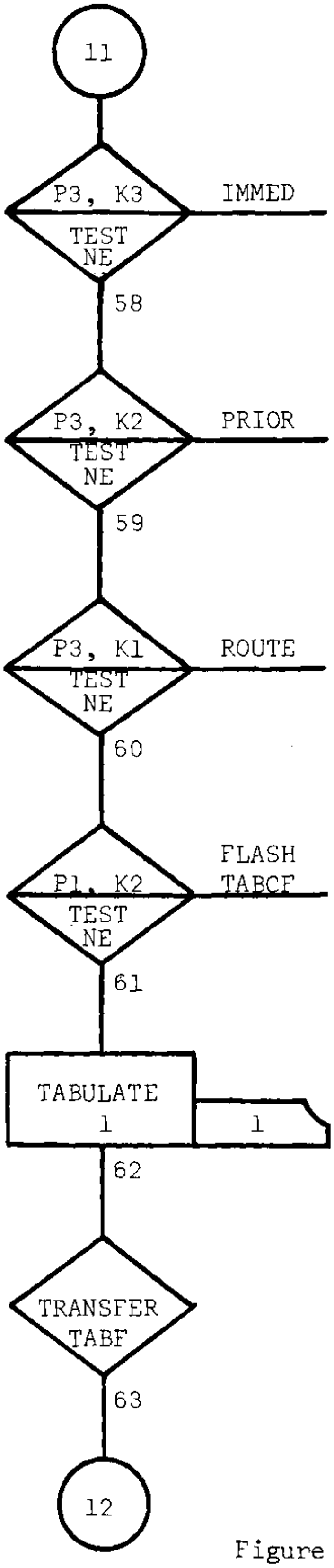
Send to Tabulate Section to calculate transit times.

NOTE: The following is the tabulation section of the model. Its purpose is to calculate the transit times for the various types of messages that have been processed. The section shown is for Priority 4 messages. There are similar sections for the remaining priorities.



If priority status is equal to 4, send to FLASH; if not, send to next block.

Figure 5. GPSS III Flow Diagram (Continued)



If priority status is equal to 3, send to IMMED; if not, send to next block.

If priority status is equal to 2, send to PRIOR; if not, send to next block.

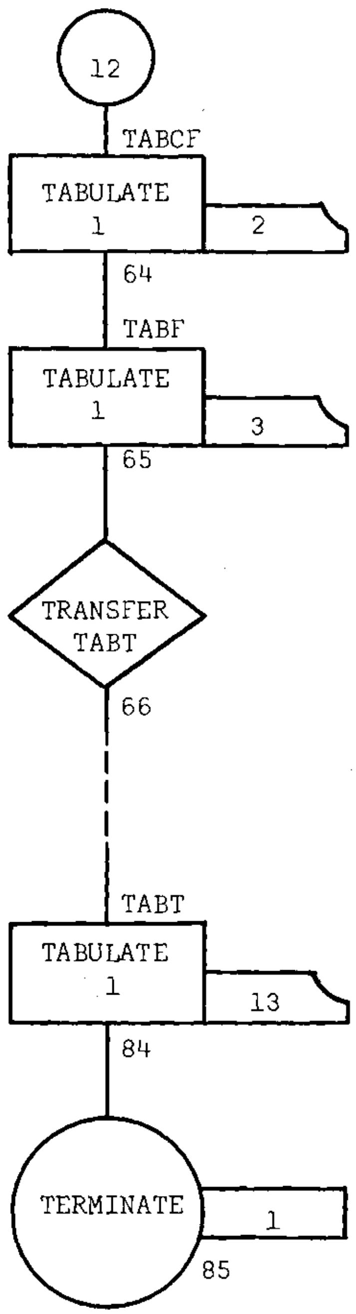
If priority status is equal to 1, send to ROUTE; if not, send to next block.

If this priority 4 message is classified, send to TABCF; if not, send to next block.

Calculate transit times for Priority 4, unclassified messages.

Send to TABF to determine the transit times for the total priority 4 messages.

Figure 5. GPSS III Flow Diagram (Continued)



Calculate transit times for priority 4 classified messages.

Calculate transit times for all priority 4 messages.

Send to TABT to determine transit times for all messages.

Calculate transit times for all messages.

Release the message from the system.

Figure 5. GPSS III Flow Diagram (Concluded)

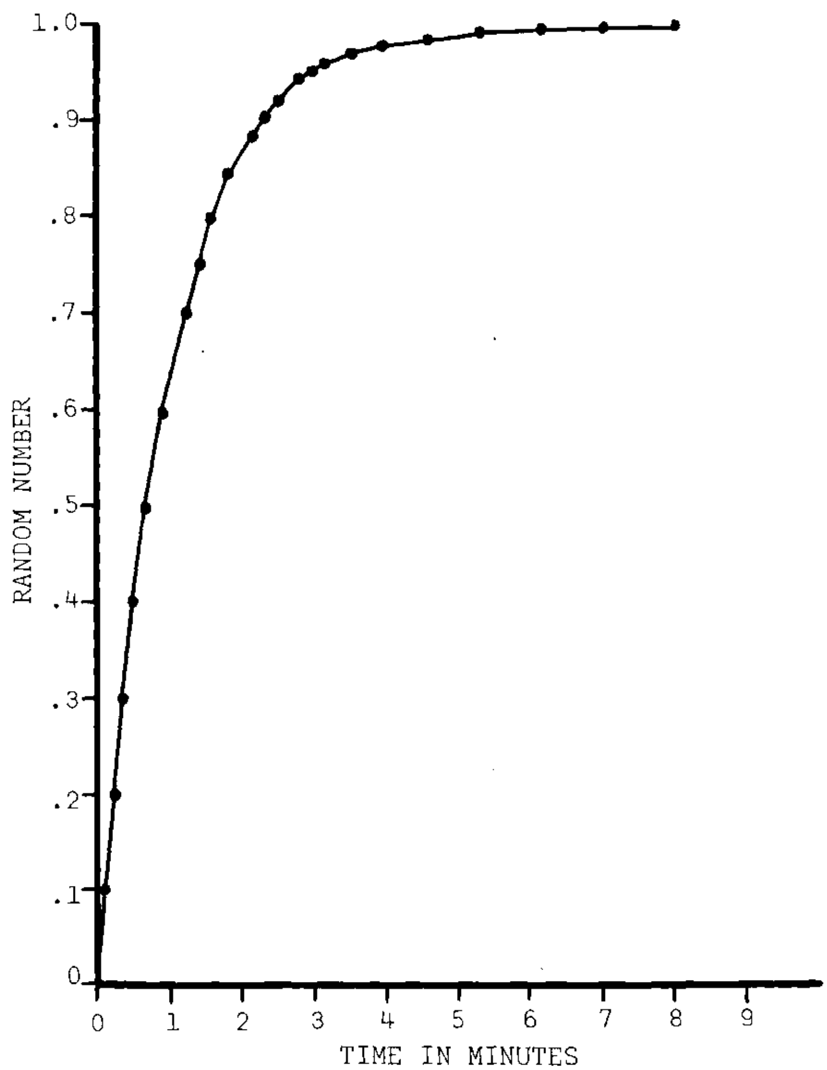


Figure 6. FUNCTION 1--Cumulative Distribution Function of the Exponential Distribution

$$F(t) = 1-e^{-t}$$

where the random variable is time and F(t) is the probability that this time is less than or equal to some specified value of time, t. In calculating the interarrival times for newly-created transactions,* FUNCTION 1 selects a random number for F(t) where $0 \leq F(t) < 1$, and then interpolates linearly between adjacent points to arrive at a value for t. This value of t is then multiplied by the mean specified in the GENERATE block, which is in this case six minutes, to give the time between the preceding transaction and the one just created.

Each service facility in the model is characterized by a set of common blocks which are used to simulate the waiting line, the dependence on precedence, and the delay caused by processing. A typical example is Service 4, block 27 through 31. As transactions are released from Service 2 they enter QUEUE 4 to be held or processed, depending on the status of the queue. Transactions are arranged by precedence within the block so that when the service facility is free, those with higher precedence are processed first. The PREEMPT block provides a means of interrupting the service of a transaction when the precedence of a message in the waiting line is higher than that of the message being serviced. The DEPART block merely reduces the number of transactions in the queue by one. The ADVANCE block is the service facility, and it delays transactions for a period of time dependent on FN4 (FUNCTION 4) and FN1 (FUNCTION 1). FUNCTION 4 is plotted in Figure

---

*A transaction in this model is defined as a message.

8. It determines the mean value of service times which are a function of the length of QUEUE 4. As in the GENERATE block, the service times are the product of the mean and some time, t, determined by the inverse of F(t), FUNCTION 1. The mean service times for the various facilities are in Table 1. The RETURN block acts as a signal to notify the other blocks that service is completed and that the ADVANCE block is vacant.

Table 1. Facility Service Times

Facility	Action	Mean Service Time
Service 1	Inspection by Supervisor	1 Min.
2	Enter in Message Center Log	2 - 3 Min.
3	Cut Unclassified Teletype Tape	4 - 8 Min.
4	Cut Unclassified Teletype Tape	4 - 8 Min.
5	Cut Classified Teletype Tape	20 Min.
6	Transmit	6 Min.
7	Transmit	6 Min.
8	Transmit	6 Min.

These five blocks are common to all service facilities where precedences determine the order of service. The first group of blocks in the flow diagram, those which pertain to Service 1, is the only exception in the program. Here transactions are processed on a first-come-first-served basis.

There are other blocks within the program which provide information and direction for the flow of transactions. One which is of interest is the ASSIGN block. There are four in the program. The first, block 6 in Figure 5, assigns the precedence of each message, in a random

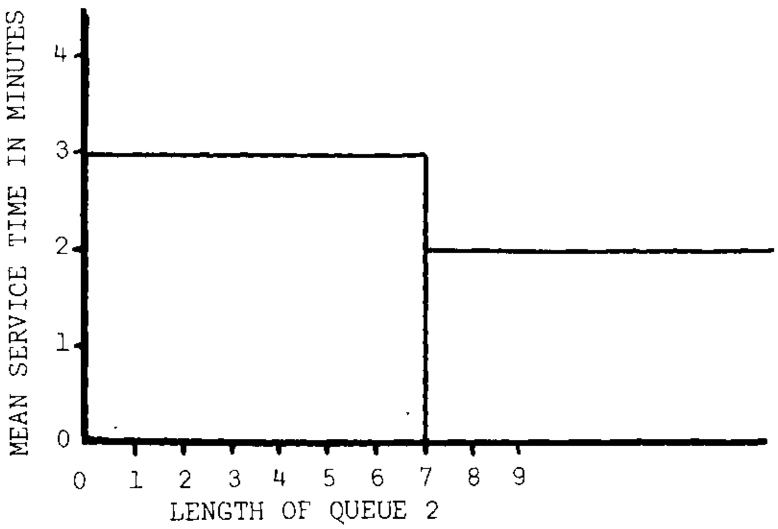


Figure 7. FUNCTION 3--Mean Service Time for SERVICE 2

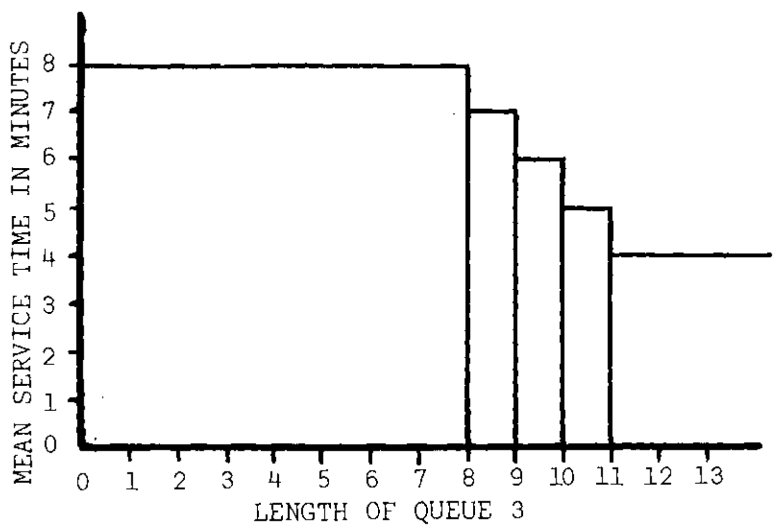


Figure 8. FUNCTION 4--Mean Service Time for SERVICE 3 and 4

manner, to Parameter 3 in accordance with FUNCTION 2 (Figure 9). The second, block 14, assigns the classification (to those messages with a priority status of 4) to Parameter 1 in accordance with FUNCTION 7 (Figure 10). The third, block 16, assigns the classification (to those messages with a priority status less than 4) to Parameter 1 in accordance with FUNCTION 5 (Figure 11). The fourth, block 17, assigns the destination to each message in accordance with FUNCTION 6 (Figure 12). These parameters are then referenced at an appropriate place in the program to direct the transaction to a particular waiting line. For example, the fourth ASSIGN block will place in Parameter 2 the number 39, 45, or 51. These are the block numbers relating to the three transmitting facilities which simulate the transmission of messages to one of the three locations. When the transactions reach the point in the program where Parameter 2 is referenced, they are sent to the block number which has been assigned to that parameter.

No additional programming is required to determine the various statistical data associated with queues and facilities. The GPSS III system package computes: the percentage utilization, the total number of transactions processed, and the average time required to process a transaction for each facility; and the maximum contents, the average contents, total number of zero entries, percentage of zeros (percentage idle), average waiting time, and the average waiting time for those transactions which had to wait for each queue are also provided.

In this problem, additional information is required concerning the time messages spend in the system, i.e., transition or transit times.

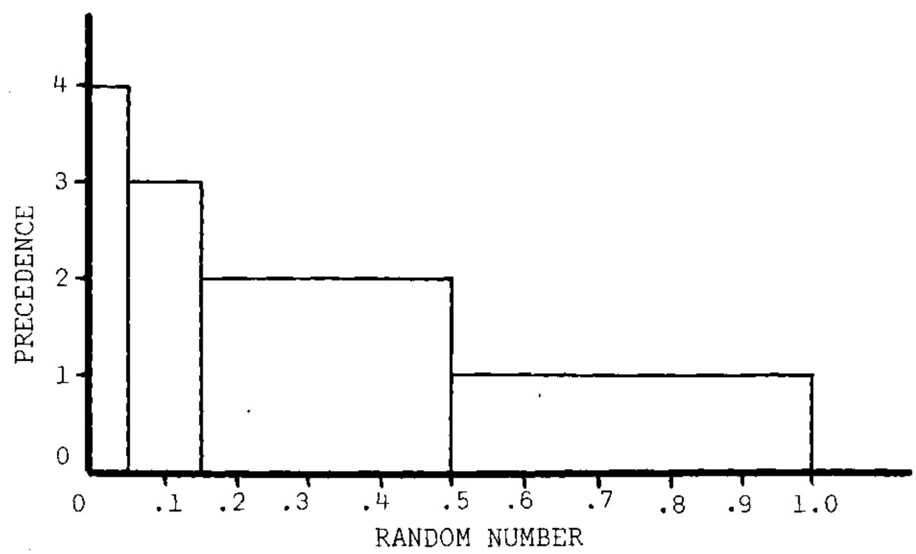


Figure 9. FUNCTION 2--Assign Precedence

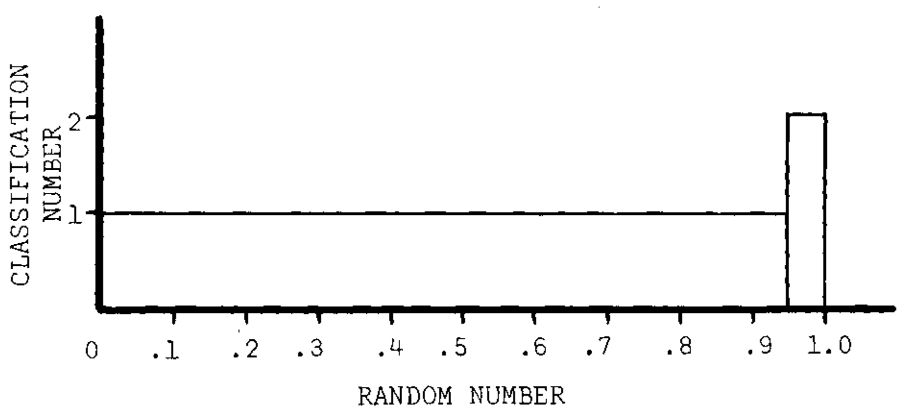


Figure 10. FUNCTION 7--Assign Classification to Flash Measures

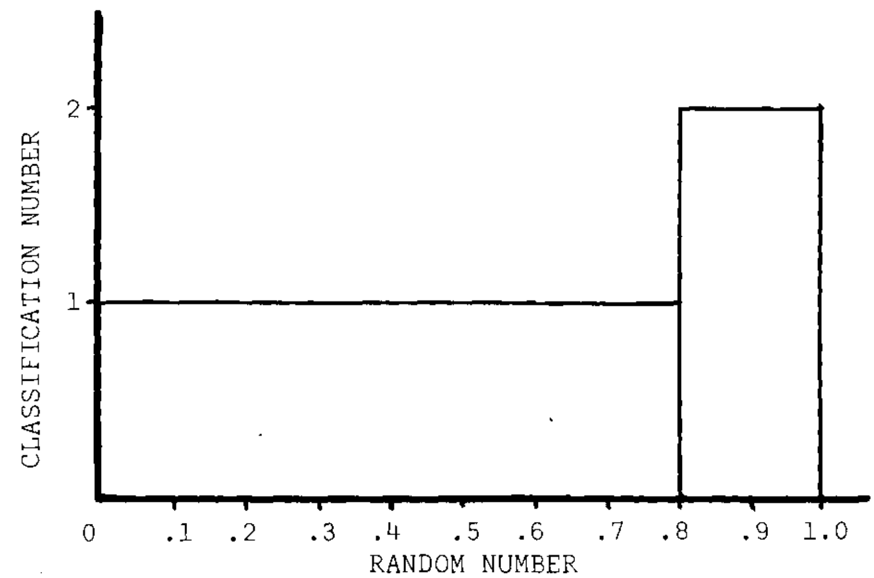


Figure 11. FUNCTION 5--Assign Classification to Immediate, Priority and Routine Messages

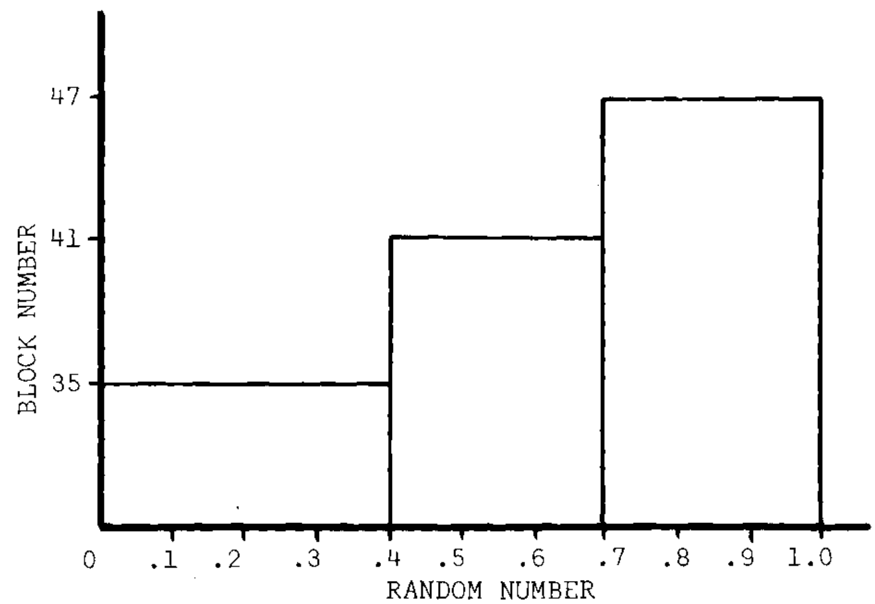


Figure 12. FUNCTION 6--Assignment of Destination

For this, a TABULATE block designating a specific TABLE is used. The model is designed to compute the transition times for: each of the eight types of messages which are generated, i.e., Flash (classified and unclassified), etc.; the total transition times for each precedence; and the total transition times for all messages.

The remaining blocks in the flow chart are self-explanatory or are similar to those mentioned above and will not be discussed. The transfer of the flow chart to a form acceptable to a digital computer is the second step in the construction of the model.

The Computer Program

The details for the compilation of the computer program will not be discussed here. The procedure is similar to that of other languages and is covered thoroughly in (25). Appendix A contains a printout of the completed program. The control cards required at the beginning and end of the program are given in (25, p. 95) for both the IBM 7040 and 7094. The 7094 was used in this research because of availability and because running time is three to four times lower than that of the 7040.*

Upon completion of the model, certain assumptions must be made about its relation with the real world system. That is, the mathematical functions and parameters which are necessary to adequately represent the action of the environment on the system and the subsequent reaction of the system to the environment must be determined. In this

---

*An estimate given by Mr. Steve Lane, an IBM Systems engineer.

first phase, particular functions and particular parameter values were selected to approximate actual events. Although empirical data are available, they are classified and inclusion in this thesis is therefore impossible. Another point to be made here is that the parameters and distributions would vary between message centers in the communication system. The distributions, arrival rates, precedences, etc., are all functions of the particular tactical and logistical units the Communication Center is supporting. The probability that two or more Communication Centers are supporting exactly the same type of units would be relatively small when considering the many different organizations within the Army area.

The primary objective of this first phase is the construction of a basic model which will later be used in a detailed study of the message center's behavior under changing conditions. The value of the parameters and the forms of the distributions are unimportant at this point; however, in Phase II (experimentation) they will be altered to provide a more general analysis.

Included in Phase I of the procedure is the validation of the model. In this discussion specific results of the initial computer run are referenced so that certain conclusions can be made regarding the acceptability of the model for further experimentation. These results and conclusions are related to those in the following chapters only in that they use the same basic model for the generation of data.

The initial computer run (the program of the basic model and the resulting data) is contained in Appendix A. To eliminate transient effects, 200 transactions were processed through the model to reach steady-state conditions. Then all queue entry counts* and facility counts** were reset to the current value and all accumulated statistics were reset to zero. One thousand transactions were then processed to yield the results for the test of the model. Of particular significance are the transit times for various types of messages (see Figure 13). It is evident that the lower the precedence the longer the message remains in the system. This is expected since the model is designed to process higher precedence messages prior to those with a lower precedence. Further inspection shows that classified messages remain in the system longer than unclassified messages. The main reason for this is the fact that the task of encrypting a message is an added step in processing and it requires considerably more time; as a result, the waiting time in the queue (Queue 5) is high compared to the other queues.

In this test the mean processing time for each type of message is well within the criteria established as a guide for message center personnel. Table 2 indicates the time required for particular types of messages to be processed, i.e., the time elapsed from receipt at the originating message center to delivery to the addressee. The time for processing at the originating message center is generally accepted at 75 per cent of these values and is listed in Table 3.

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*A cumulative count of transactions.

**A cumulative count of transactions entering the facilities.

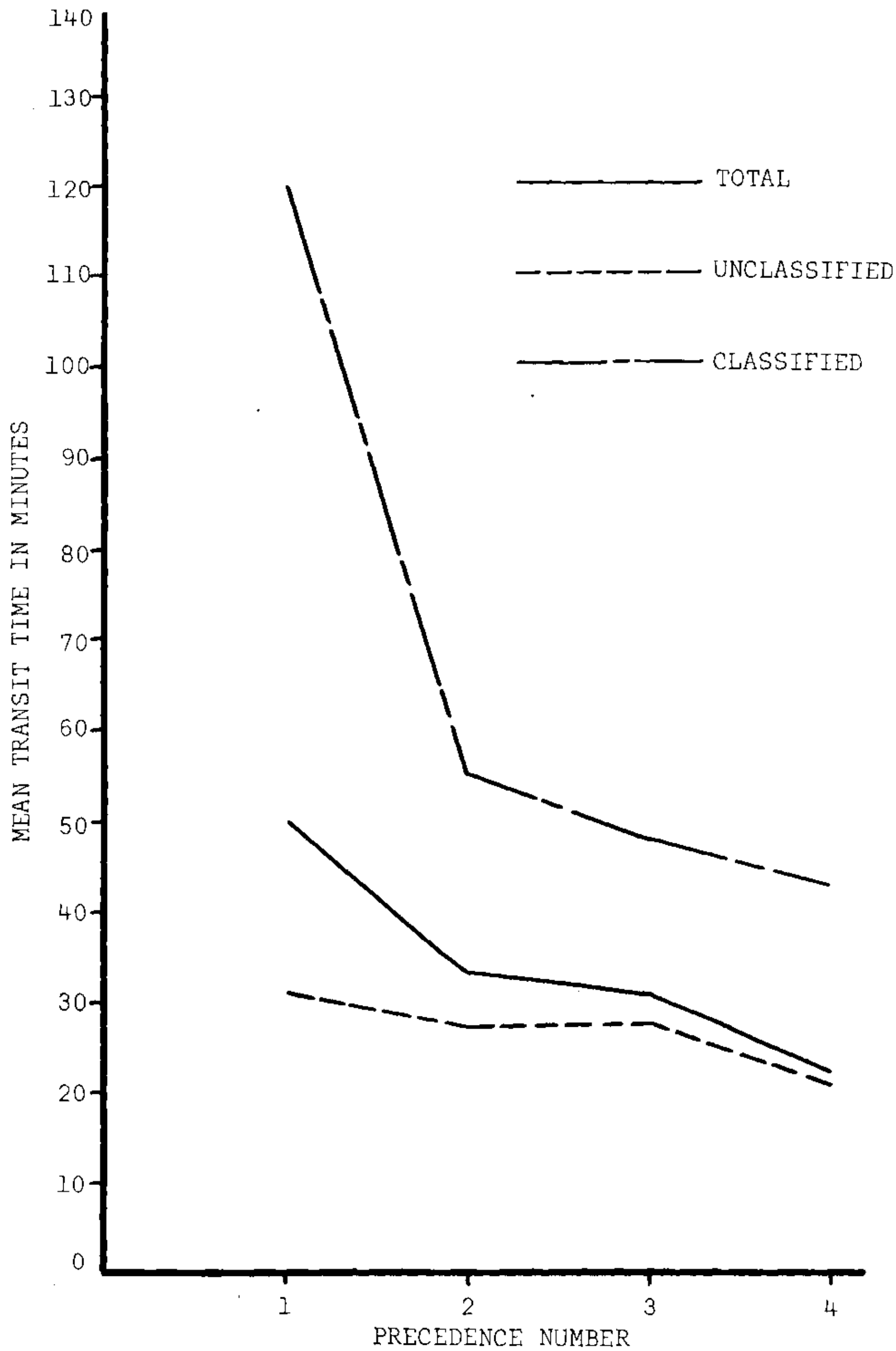

Figure 13. Mean Transit Times in Minutes for each Precedence

Table 2.* Maximum Mean Processing Times

PRECEDENCE	PRECEDENCE NUMBER	SPEED OF SERVICE
FLASH	4	As fast as possible
IMMEDIATE	3	30 Minutes to one hour
PRIORITY	2	1 - 5 Hours
ROUTINE	1	3 - 8 Hours

Table 3. Maximum Mean Transit Times

PRECEDENCE	PRECEDENCE NUMBER	SPEED OF SERVICE **
FLASH	4	As fast as humanly possible
IMMEDIATE	3	Not more than 45 minutes
PRIORITY	2	Not more than 3 hours and 45 minutes
ROUTINE	1	Not more than 6 hours

Table 13 in Appendix A shows the transit times for the total of 1,000 messages. Of particular interest is the relatively high standard deviation. As will be seen in later experiments, this is the case where a large portion of the messages have a low precedence (50 per cent Routine in this model). Morse explains this for a two-priority system (31, pp. 128-133) as being the result of increased delay times for the non-priority transactions. This occurrence is more evident when

*This table was extracted, in part, from (24, p. 449).

**The maximum acceptable mean service time for the processing of messages within the originating message center.

considering the coefficient of variation (standard deviation ÷ mean) for the transit times of each precedence (Figure 14). This indicates that even though the mean increases for the lower precedences, the standard deviation increases at a faster rate.

Phase I of the procedure is thus described. The model was constructed and tested, and it performed in a manner acceptable as an approximation to a real world system operating under similar conditions. This validation is subjective, and it is largely based on the experience of the researcher.

Experimentation: Phase II

It clarifies the procedure if, at this point, the objectives are restated in terms of what the Army Signal Officer must know about the system and the environment prior to committing a Communication Center to an area of responsibility. Ideally, this information is:

1. The expected time between arrivals for messages entering the message center along with an estimate of an approximate probability distribution.

2. The percentage of messages that are classified.

3. The precedence mix.

4. The organization of the message center, i.e., the personnel and equipment available to the Message Center Officer.*

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*This information is usually available in the appropriate TOE; however, there are other documents the Signal Officer must consult. In this case, a very important report is an equipment status report which lists all authorized equipment, and, in addition, serviceable and unserviceable equipment for particular units. Therefore, even though a message center is authorized certain items, they may not all be available.

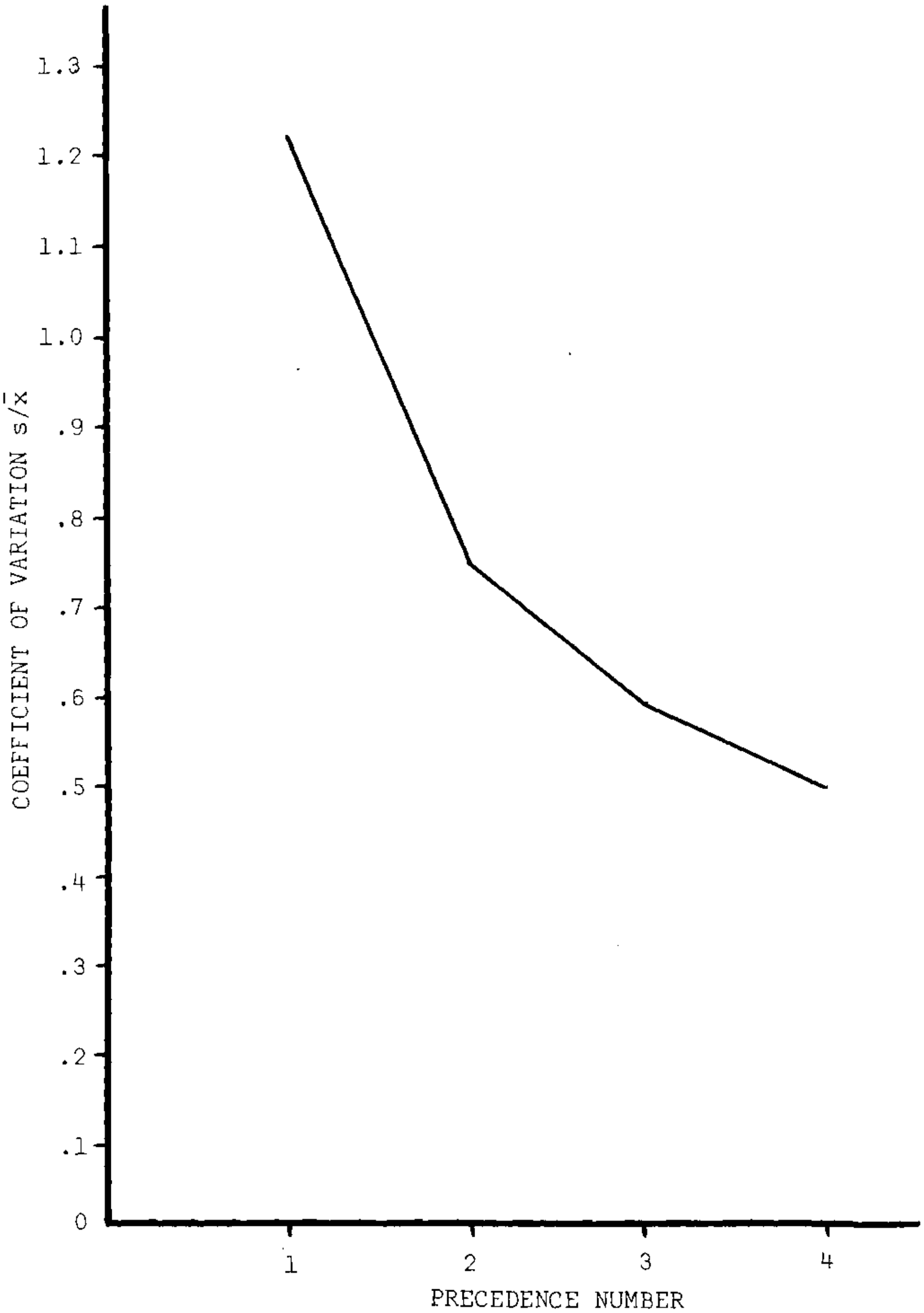

Figure 14. The Coefficient of Variation of the Transit Times for each Precedence

5. An estimate of the ability of the message center to process the input within the criteria established in Table 3.

Paragraph 5 above is a succinct statement of the objective of the thesis. By using the model constructed in Phase I and varying the input (determined by 1, 2, and 3 above) the ability of a particular organization to effectively* process messages (under the stated conditions) can be approximated.

To insure a thorough understanding of the relationships which affect the input in a particular environment and the values they will assume in the ensuing experiments, consider the following:

1. Distribution of interarrival times: The assumption has been made that the interarrival times are independent random variables described by some probability distribution. For this research the Gamma density function

$$f(t) = \frac{\lambda}{\Gamma(r)} (\lambda t)^{r-1} e^{-\lambda t} \text{ for } t > 0$$

and $f(t) = 0$ for $t \leq 0$,

was chosen to approximate the interarrival times. This is a two-parameter family of curves where r is the shape parameter and λ is the scale parameter. The mean is $E(t) = \frac{r}{\lambda}$, and the variance is $V(t) = \frac{r}{\lambda^2}$

---

*The term *effectively* or *effective* is used throughout this thesis to describe the ability of the system to process messages. The system is considered to be operating effectively if the mean processing times are within the criteria specified in Table 3, and is considered to be operating ineffectively if the mean processing times exceed these criteria.

(2, p. 84). When r = 1, the gamma distribution becomes the exponential distribution. When r is a positive integer, the Gamma is identical to the Erlang distribution (32, p. 88). This is an important concept since the distribution function of the Gamma does not exist in closed form. Therefore, to generate Gamma random variates, generate Erlang variables by summing r independent exponential variates, $t_1, t_2, \ldots, t_r$, each with the same expected value, $1/\lambda$. The Gamma variate can then be expressed as,

$$t = 1/\lambda\ t_1 + 1/\lambda\ t_2 + \cdots + 1/\lambda\ t_r = 1/\lambda \sum_{i=1}^{r} t_r$$

where each t_i is randomly selected from the exponential distribution function, $F(t_i) = 1 - e^{-t_i}$. $F(t_i)$ is assigned a random number RN, $0 \le RN < 1$ and each t_i is calculated from $t_i = \ell n[1\text{-}RN]$, the inverse function.

The generation of these variates in GPSS III turns out to be a relatively simple process. Specifying two exponential distribution functions as $F_1(t)$ and $F_2(t)$ and multiplying each value in these functions by a multiple of 10, say 10^3, so that all values are integers* we develop two associated functions (call them $G_1(t)$ and $G_2(t)$). Next, define a variable (V_1) as $V_1 = G_1(t) + G_2(t)$ (for the case where r = 2).

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*All arithmetical operations in variable statements in GPSS III truncate numbers to the nearest integer prior to performing the designated operation (25, p. 56). Therefore, to maintain an acceptable accuracy, these numbers are changed to integers.

Using V_1 as the input to another function, say H(t), where $H(t) = V_1 \div 1000$, we have a linear transformation back to decimal values. H(t) is then used as input to the GENERATE block in the creation of interarrival times for messages entering the system. The sequence of operations in the GPSS III language is:

1 FUNCTION	RN1, C48	$G_1(t)$ = integer values of $F_1(t)$
2 FUNCTION	RN1, C48	$G_2(t)$ = integer values of $F_2(t)$
1 VARIABLE	FN1 + FN2	$G_1(t) + G_2(t)$
3 FUNCTION	V1, C36	$H(t) = V_1 \div 1000$
GENERATE	$1/\lambda$, FN3	$1/\lambda = E(t) \div r$

If it is desired to increase r, to say 5, then additional variable statements can be defined as:

1 VARIABLE	FN1 + FN2 + V2
2 VARIABLE	FN1 + FN2 + V3
3 VARIABLE	FN1

The alteration of r produces a change in the shape of the Gamma distribution so that by changing either E(t) or V(t), or both, and calculating

$$r = \frac{(E(t))^2}{v(t)}$$

a wide variety of distributions can be simulated (2, p. 72).

2. Percentage of messages which are classified: By varying the percentage of messages which are classified, only three facilities in the message center are affected. These are facilities 3 and 4 which cut teletype tapes for unclassified messages, and facility 5 which cuts teletype tapes for classified messages. However, as will be seen in the following chapter, the system is extremely sensitive to changes in this parameter.

3. The precedence mix: Morse states (31, p. 132)

> . . . imposition of priorities increases the mean number of non-priority units present and makes their average wait in line longer, whereas it usually shortens the queue and delay of the priority item. If the overriding requirement is to reduce delay for one particular class of unit, then this class should be given priority.

This is the Army's reason for assigning precedences to messages; that is, to shorten delay times for certain types of messages. This thesis is not necessarily concerned with shorter delay times, but rather the increased delay times of the low precedence messages and the effect they have on the operation of the system.

The combinations involved in varying the above parameters are infinite; therefore, only a few were chosen to provide a representation of the total. For the remainder of this thesis, let the following represent the parameters indicated:

1. $E(t)$ = mean value of the time between arrival of messages to the message center.

2. r = shape parameter for the Gamma Distribution.

3. λ = scale parameter of the Gamma Distribution.

4. C = ratio of classified messages.

5. P = a particular precedence mix and P = (F, I, P, R) where F, I, P, and R are the ratios of Flash, Immediate, Priority and Routine messages, respectively, and F + I + P + R = 1.0.

Experiment 1

The first experiment conducted was made to test the effects of varying r and C on the transit times of messages with specific precedences. The shape parameter, r, was given five different values (1, 2, 4, 5, 10), and C three values (0.2, 0.3, 0.4). P was varied over a wider range and the values are listed in Table 8, Appendix E.

For ease in identifying the many computer runs involved, let a particular run be designated by "test (i,j) Model n" where i is the i^{th} value of r, j is the j^{th} value of C and n is the model number listed in Table 8. A particular run could be denoted by Test 43 Model 10, where r = 5, C = 0.4, and P = (0.25, 0, 0.75, 0).

Experiment 2

Experiment 2 was designed to test the effects of varying P on the transit times of messages. Here r was held constant (r = 1), C was given the same values as in the preceding experiment and P was given the values listed in Table 9, Appendix E.

Experiment 3

To test the null hypothesis that there are no effects from varying C and P, Experiment 3 was designed to analyze the variance of the transit times for the different types of messages. The experiment is shown in Figure 15. It is a randomized block design where the Model to be tested is

		CM_l					
		0.4		0.3		0.2	
		C_k					
P_j	PM_i	Uncl	Clas	Uncl	Clas	Uncl	Clas
Flash	0.01 - 0.24						
	0.25 - 0.49						
	0.50 - 0.74						
	0.75 - 1.00						
Immediate	0.01 - 0.24						
	0.25 - 0.49						
	0.50 - 0.74						
	0.75 - 1.00						
Priority	0.01 - 0.24						
	0.25 - 0.49						
	0.50 - 0.74						
	0.75 - 1.00						
Routine	0.01 - 0.24						
	0.25 - 0.49						
	0.50 - 0.74						
	0.75 - 1.00						

Figure 15. Design of Experiment 3

$$X_{ijklm} = \mu + PM_i + P_j + C_k + CM_l + PMP_{ij} + PMC_{ik} + PMCM_{il} + PC_{jk} +$$

$$PCM_{jl} + CCM_{kl} + PMPC_{ijk} + PMPCM_{ijl} + PMCCM_{ikl} + PCCM_{jkl} +$$

$$PMPCCM_{ijkl} + \varepsilon_{ijklm}$$

where PM_i is the particular precedence mix in which an observation falls and CM_l is the classification mix. For instance, the mean transit time for a group of observations, where the messages in the group were selected from a population in which the percentage of Flash messages was between zero and 24 per cent, and from which 60 per cent were unclassified, would go into cell $i = 1$, $j = 1$, $k = 1$, $l = 1$, or the cell in the upper left corner of Figure 15. Since the observations were mean times, the distribution of the values in each cell is normal by the Central Limit theorem (43, p. 155). For this experiment four replications were made for each cell with each replication giving the average value from a particular computer run.

Experiment 4

Experiment 4 was designed as an attempt to construct a predictive model for the times the various messages spend in the system. Two types of probability distributions, lognormal, and Weibull were selected to fit the distribution of the observed data. The purpose of this was to establish some correspondence between the input and the output. Table 10, Appendix E, contains the values of the parameters that were used.

Experiment 5

The last experiment was conducted to determine the effects of reducing the mean interarrival times to further determine the point at which additional facilities would be required to process the additional messages in the system. The following parameters and their values were held constant throughout this test:

1. $r = 2$
2. $P = (0.05, 0.10, 0.35, 0.50)$

The mean interarrival time $E(t) = r/\lambda$ was given the following values: 360, 300, 240, 180, 120 and 60 seconds. The percentage of classified messages was 30, 60, and 90 per cent. The number of facilities for processing classified messages was increased in each test by one until a maximum of four was reached. Because of the physical limitations of the equipment involved, no more than four classified facilities can be employed (24, p. 331). For cases where more facilities are required, another complete Communication Center or a different type of unit would have to be committed.

A variation of Experiment 5 was used to determine the effect of changing an unclassified facility to a classified one when the mean processing time for classified messages reached a certain point (180 min.). Though this procedure is not feasible in practice, the results proved interesting as will be seen in Chapter IV.

In Phase II a total of 535 models were processed through the IBM 7094 system, a number considered sufficiently large to make valid conclusions concerning the operation of the system.

CHAPTER IV

RESULTS

The objective is to determine the point at which the basic modeled system becomes unacceptable given certain operating conditions. As stated earlier, this is the point where the mean transit time of a particular type of message (Flash, Immediate, etc.) exceeds the criteria established in Table 3.

Experiment 1

The results of Experiment 1, variation of r, C and P are contained in Tables 11 through 25 in Appendix E. These tables list the mean transit times by precedence for each value of r and C used. The values of the parameters used in this experiment are those listed in Table 8.

The mean values of the mean transit times for each precedence and each test and trial are contained in Table 26, Appendix E. A graphical representation of these values is depicted in Figures 16 through 20. Here it is obvious that the reason for congestion in each test (each value of r) is caused by increasing C; and further, the precedence which is affected is Routine (precedence Number 1). Figure 21 is a graph of the means of each precedence over the three trials (values of C). These values are contained in Table 27, Appendix E. The effects caused by varying r can be seen. Although there is some

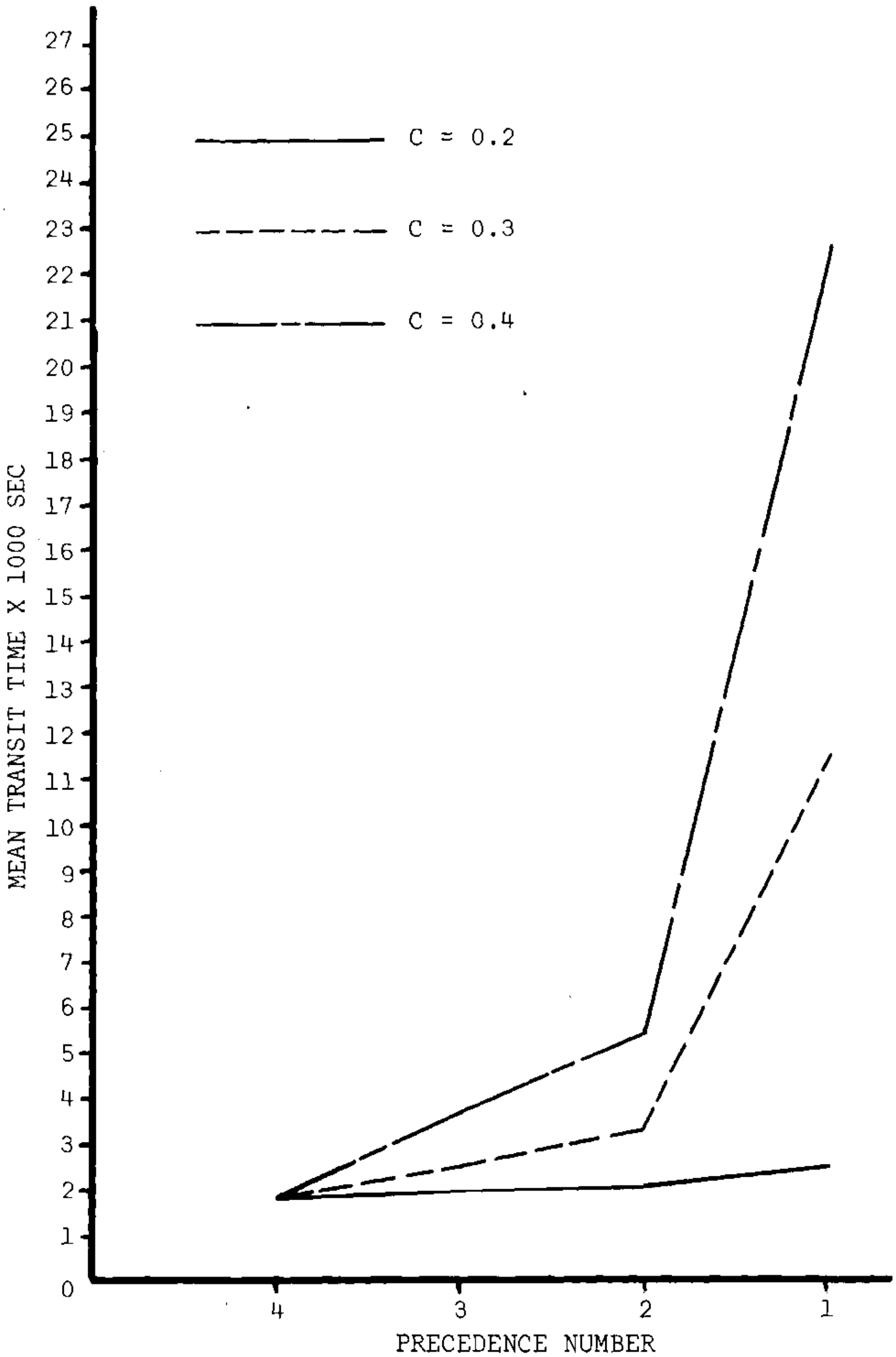

Figure 16. Mean Transit Times for r = 1

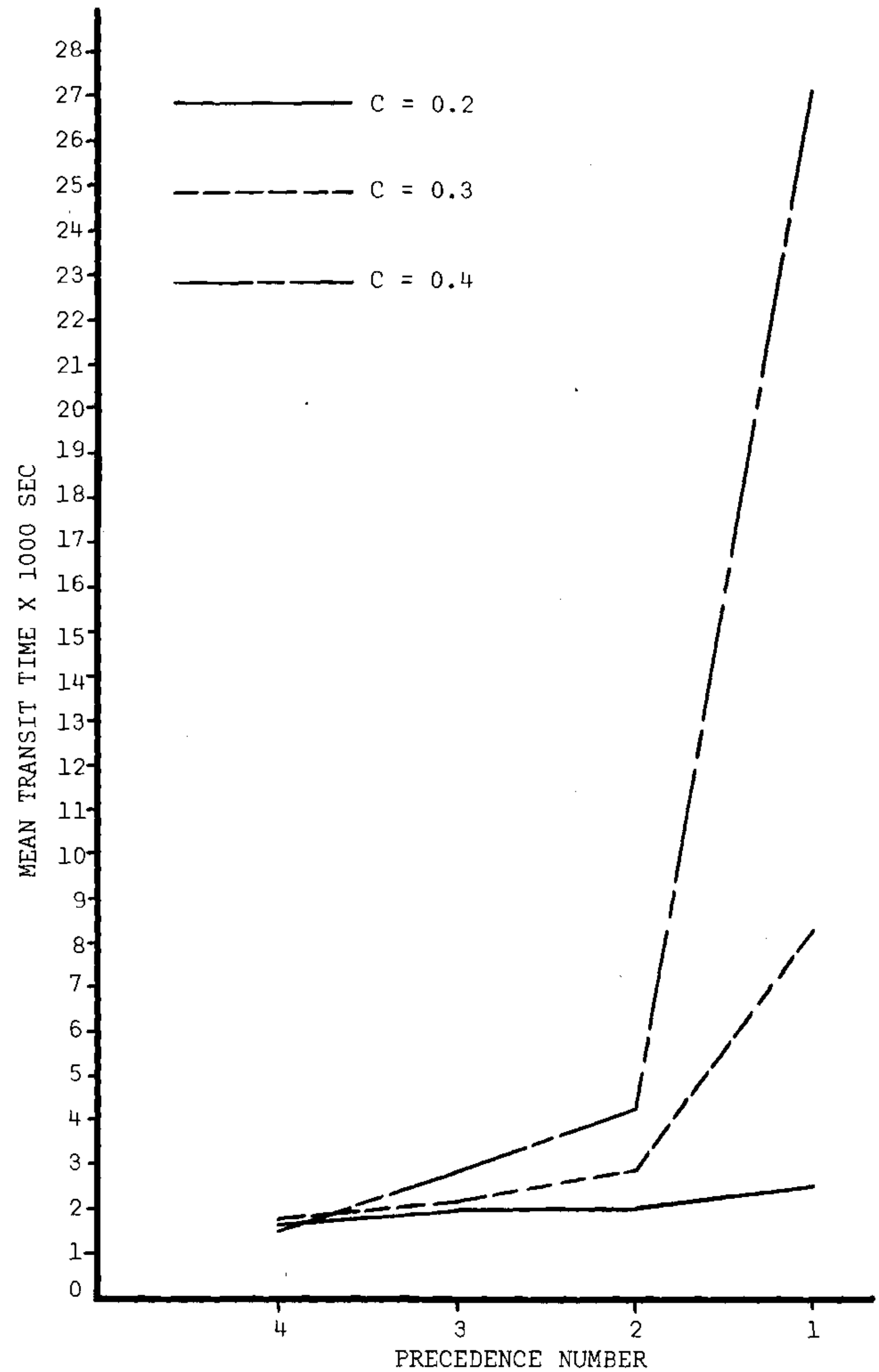

Figure 17. Mean Transit Times for r = 2

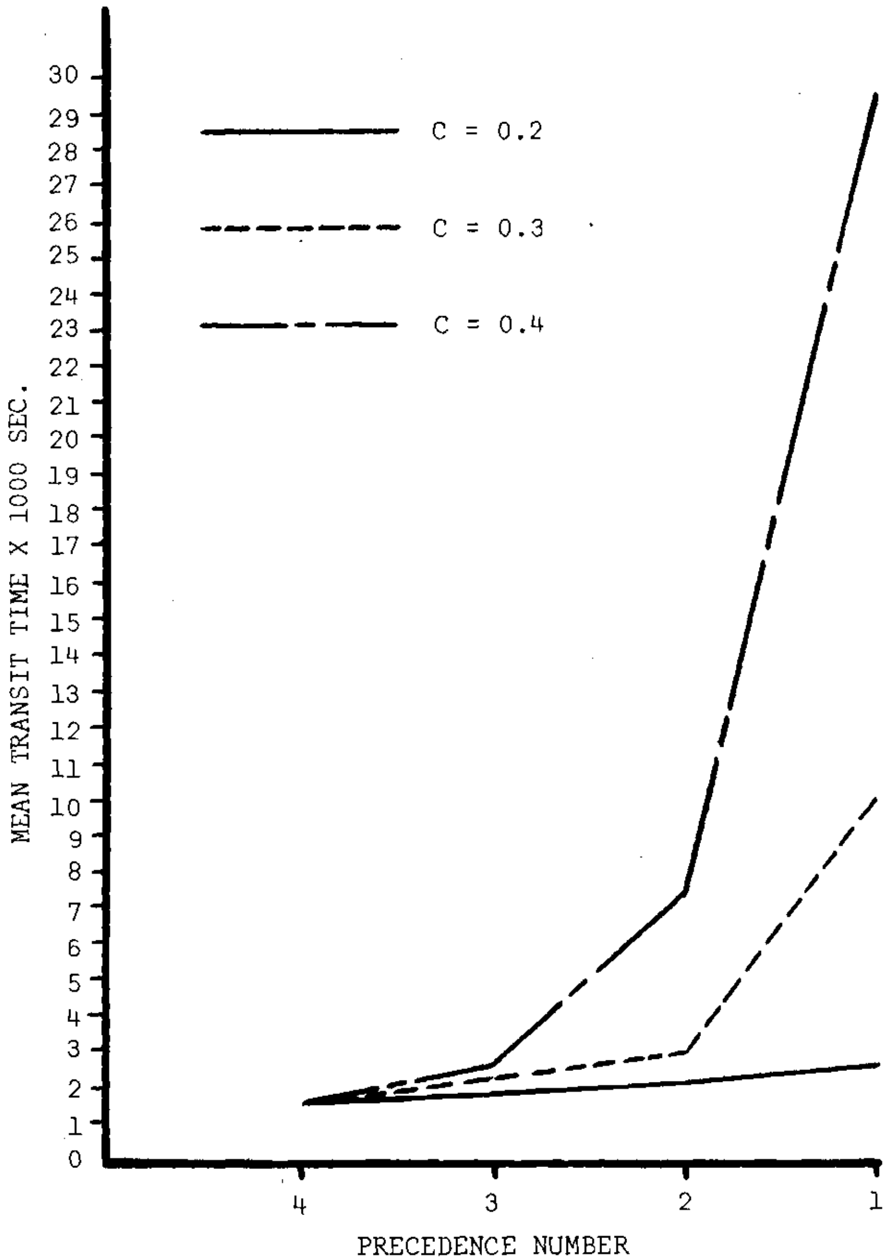

Figure 18. Mean Transit Times for r = 4

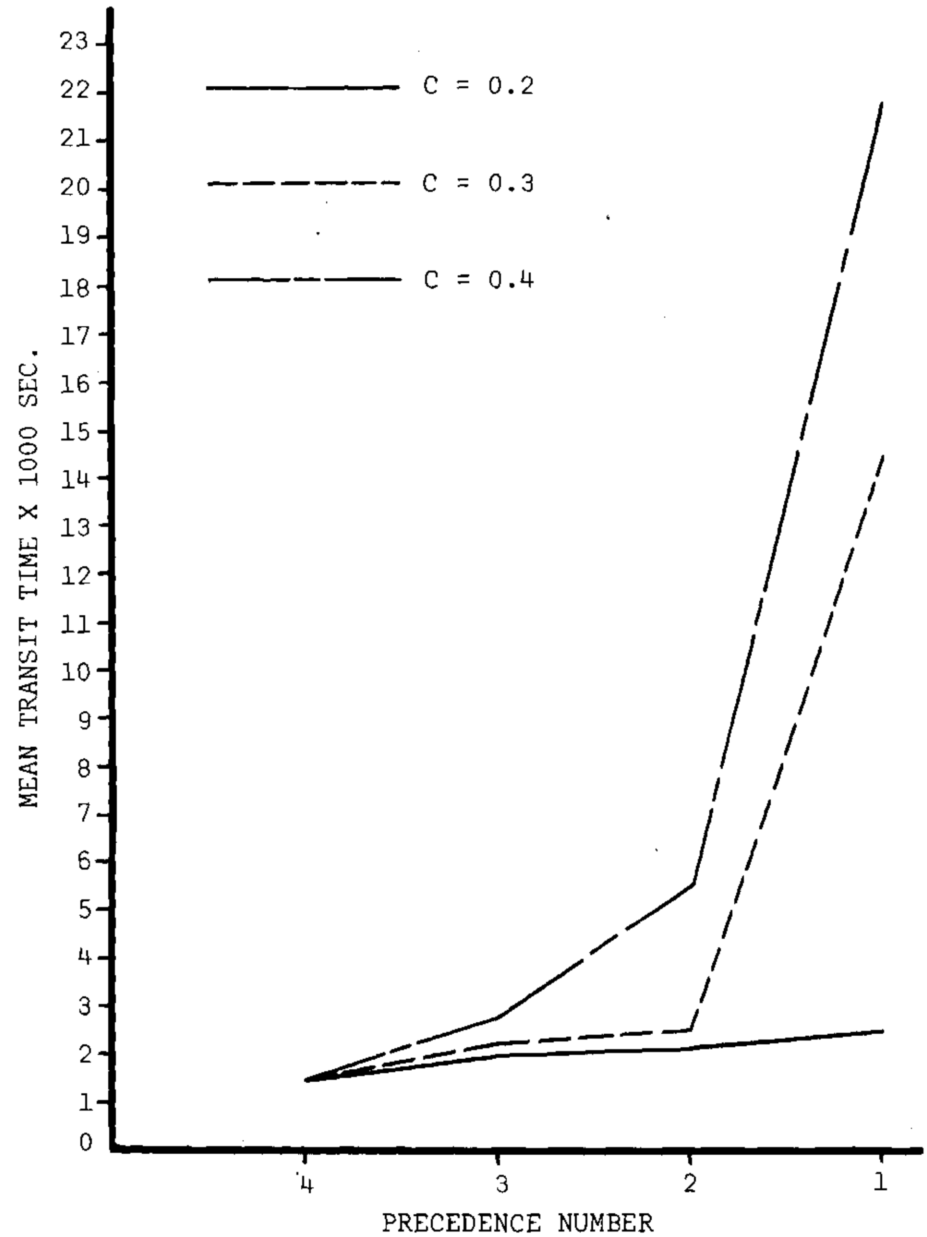

Figure 19. Mean Transit Times for r = 5

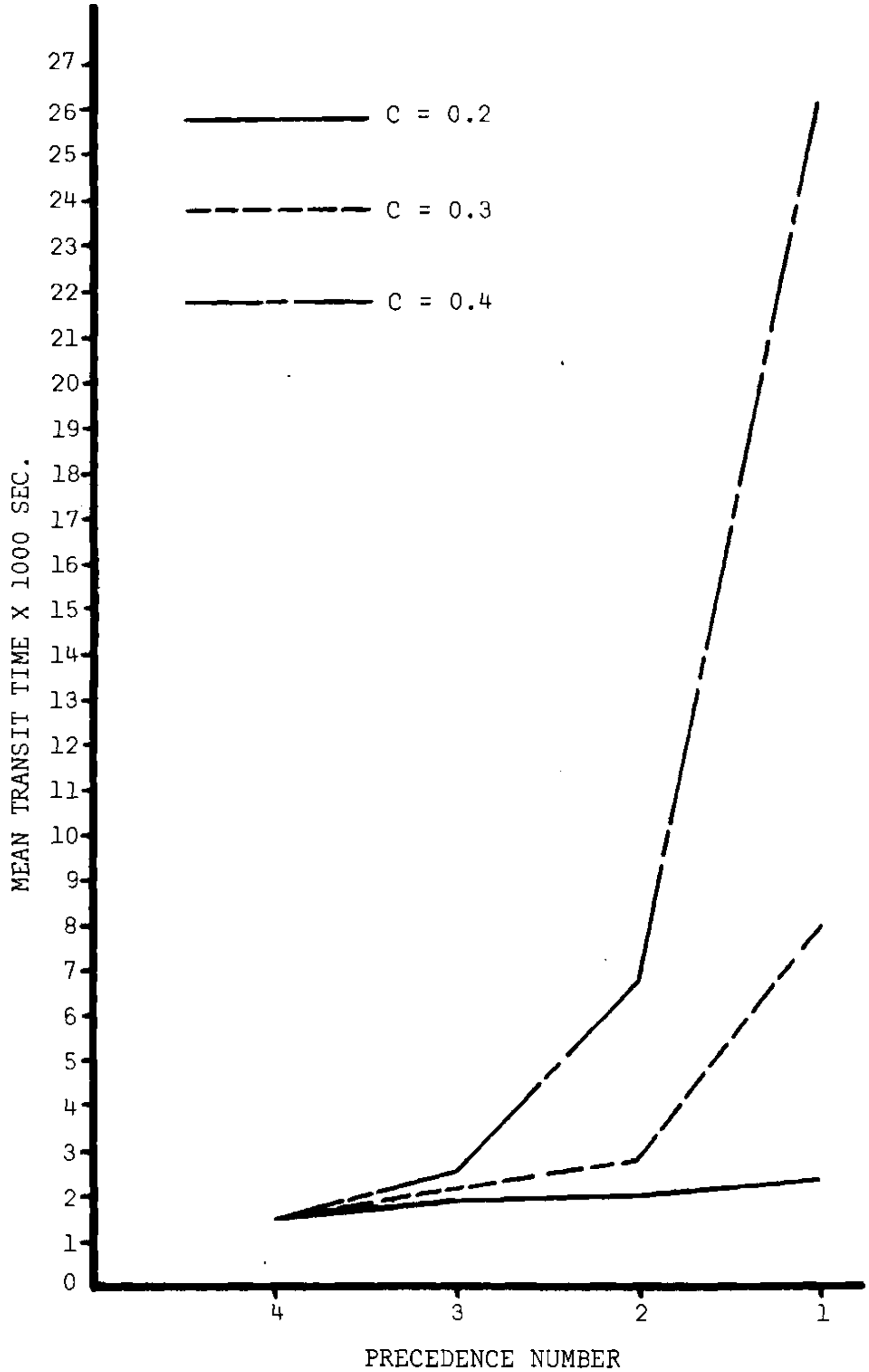

Figure 20. Mean Transit Times for r = 10

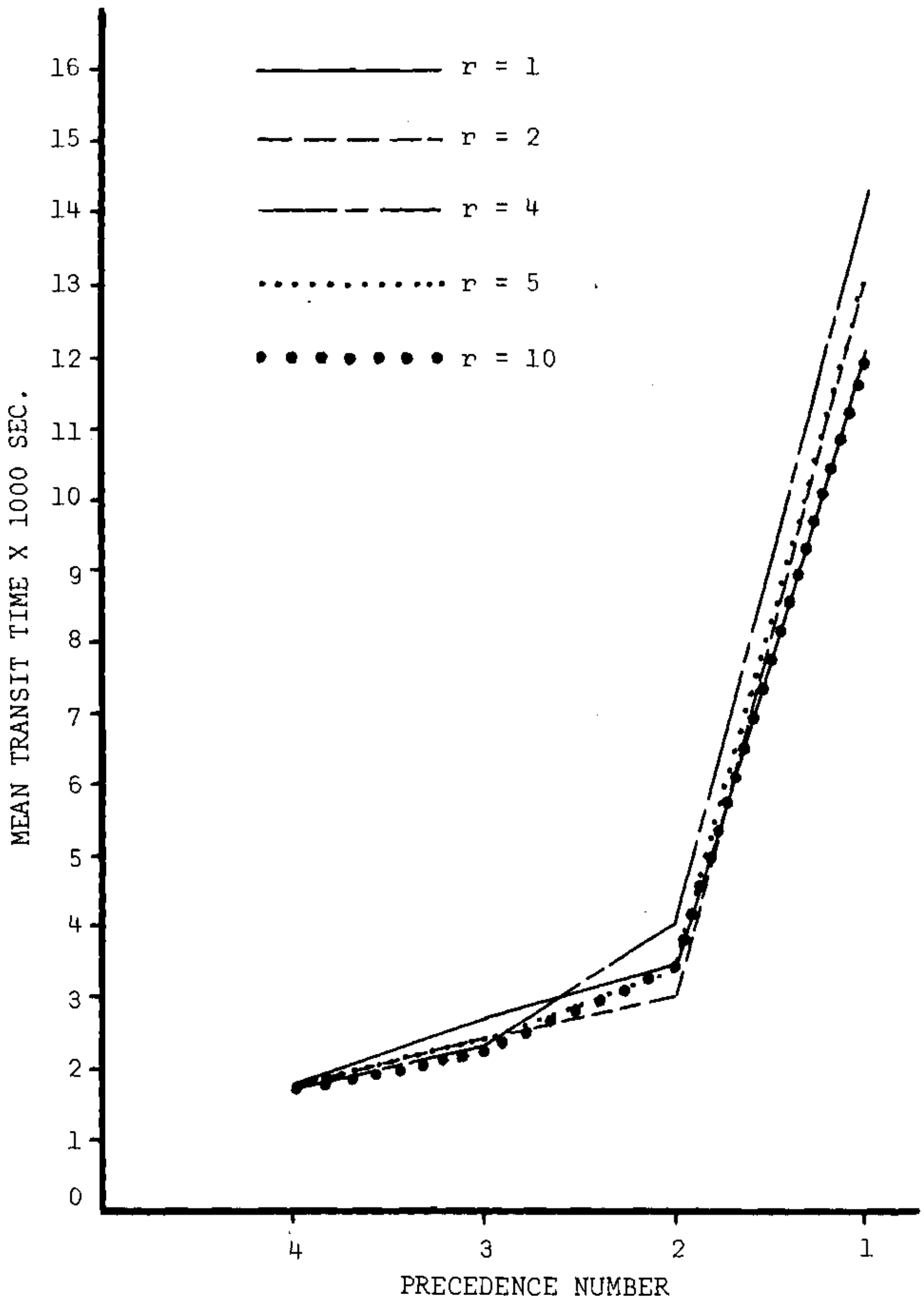

Figure 21. Mean Values of the Mean Transit Times for each Test

variance between each r, the major difference is between precedences, particularly between Priority and Routine. Therefore, when congestion does occur, it is generally caused by an increase in transit times for Priority and Routine messages. Morse (31, p. 126) shows, for the case of two priorities, that the reason for this is increased delay times for the non-priority item. Since it has been determined that increasing the percentage of classified messages in the system increases the transit times for particular types of messages, then the additional delay must be caused by the classified message facility. In the model, this is Service 5. If the mean waiting time is computed for each test and trial for messages entering Queue 5 (Table 28, Appendix E) and then graphed (Figure 22), the origin of the delay is evident. In comparing the mean waiting times in the unclassified facilities (Service 3 and 4) with that of Service 5 for the case where C = 0.4, the difference is even more obvious (Figure 23).

Experiment 2

Experiment 2 described in Chapter III was used to generate data to determine the point that particular precedences exceed the criteria specified in Table 3. The mean transit times for each precedence in each model were examined and those that were not less than the maximum allowable are tabulated and discussed as follows:

1. Table 29, Appendix E, contains the process times that were unacceptable when C = 0.2. In each case it was the concentration of Flash messages that caused the additional delay. The system was not saturated; in fact, the utilization of any one facility did not exceed

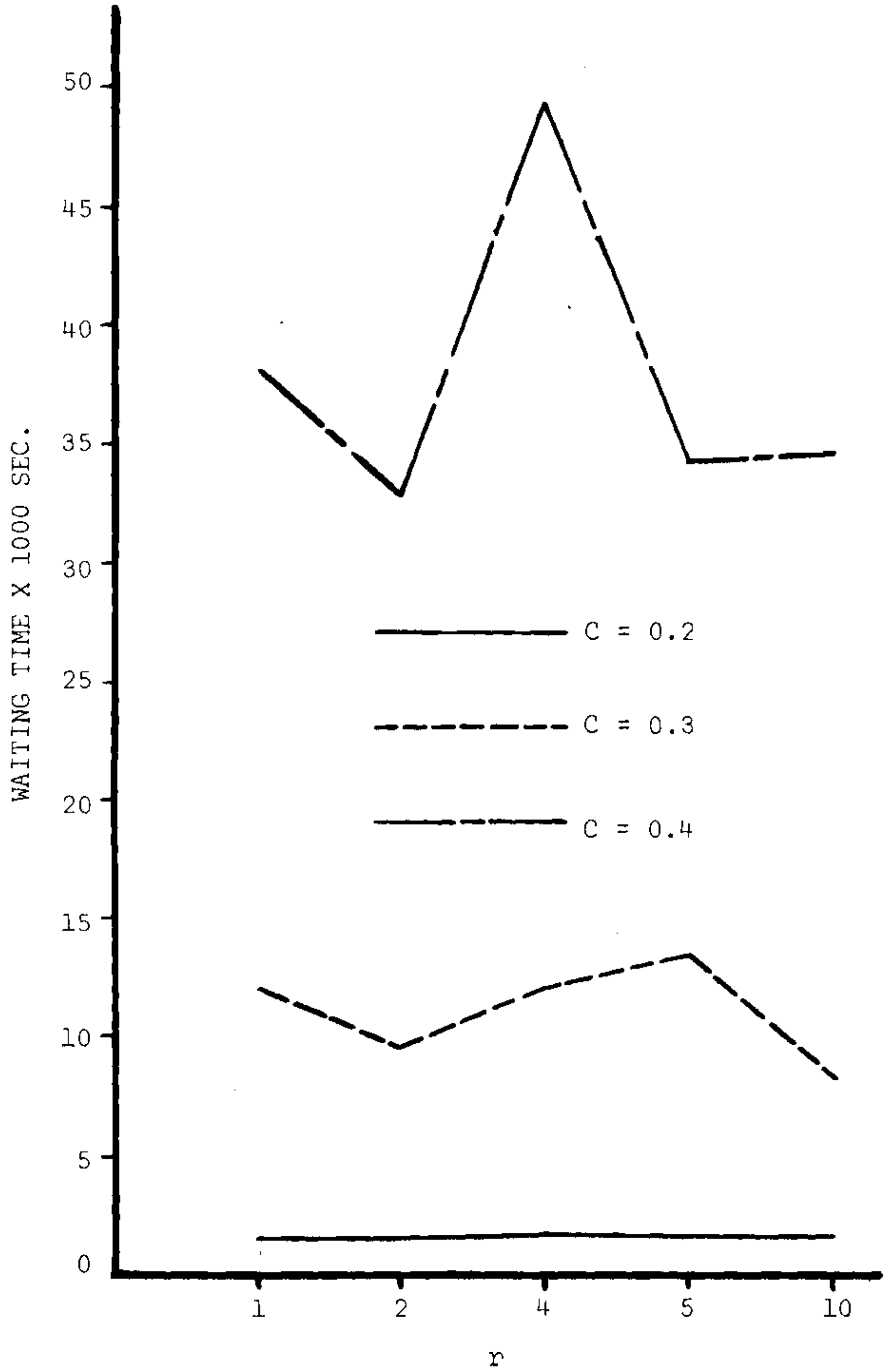

Figure 22. Mean Waiting Time in Queue 5

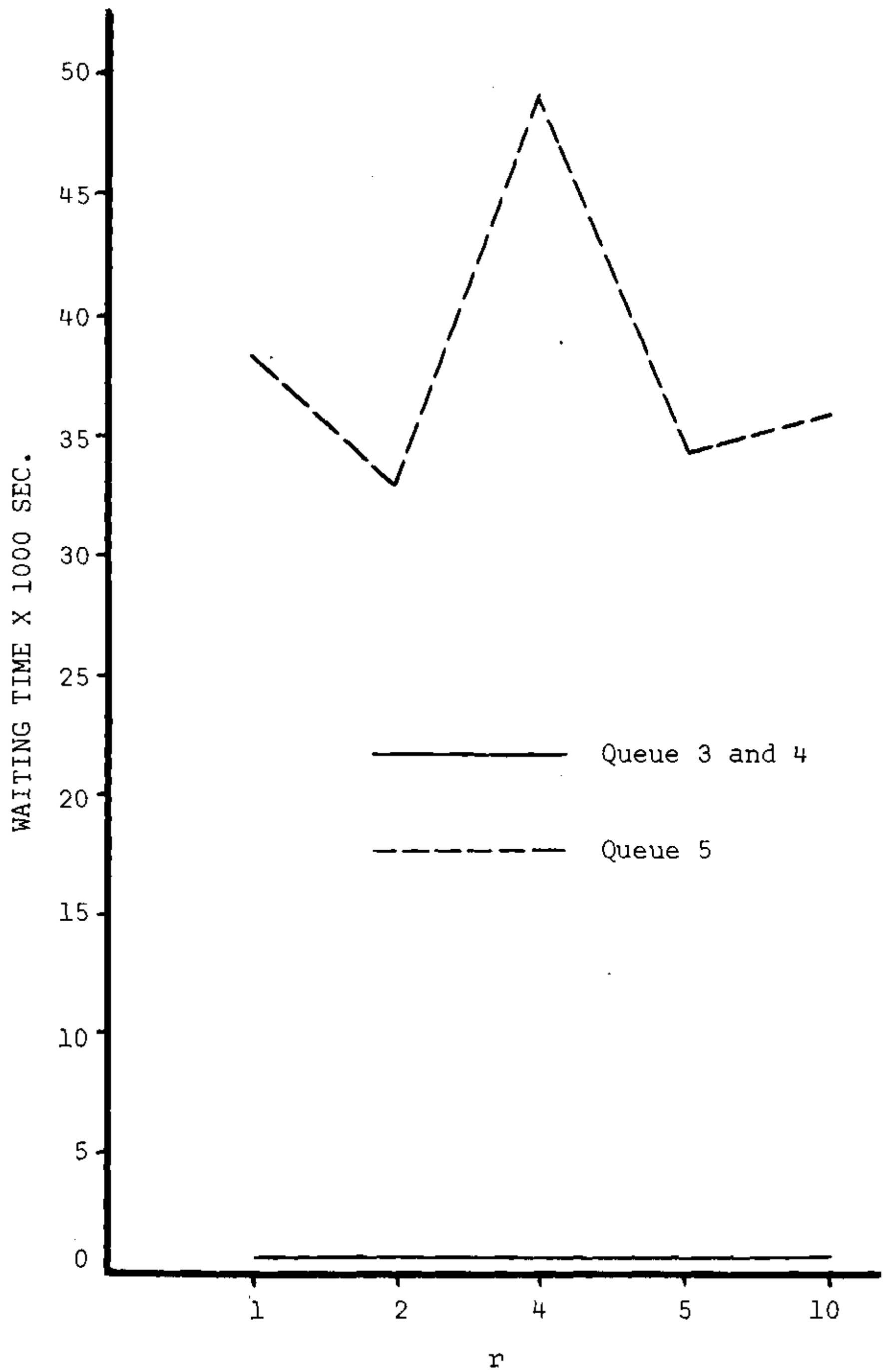

Figure 23. Mean Waiting Times for Tape Cutting Facilities

81 per cent in all three models.

2. When C was increased to 0.3, a total of 21 models were found to be unacceptable. Table 30, Appendix E, lists these models and the transit times for the precedence indicated. The excessive delays in the first seven models in the table were caused by 100 per cent utilization of Service 5 (classified tape facility). In each model it was the transit times of the Routine (the lowest precedence) messages that were unacceptable, and in each case the cause can be traced to the saturation of Service 5. Morse shows (31, p. 125) that for a two-priority system the mean waiting time for priority units is finite as the utilization of the facility approaches unity, but is infinite for the non-priority unit. It appears, then, that the excess delay times for the low priority units is caused by one or more of the facilities being saturated. This is not the only reason, however. Model 66 in Table 30, Appendix E, shows that the mean transit time for Routine messages is 686 minutes, but the maximum utilization of any one facility is only 96 per cent (Service 5). This model has a low percentage of Routine messages, and Table 9, Appendix E, indicates that there are several others. The reason the others are acceptable and Model 66 is not lies in a deficiency in the basic model. For example, consider Model 29 where P = (0, 0.2, 0.75, 0.05) and C = 0.3. Theoretically, 50 Routine messages should have been generated and of these 15 should have been classified and processed through Service 5. The computer run shows that 30 were processed and none of these were classified. This indicates that all classified Routine messages were detained at Service

5 and were unable to obtain the facility because higher precedence messages were being processed. The utilization of Service 5 was 99.9 per cent, and the average contents of the queue preceding it was 35. Therefore, it is likely that there was never an instance when a Routine message could enter the facility. The only inference that will be drawn from this observation is to reject these computer runs since there is evidence that the sample taken is not structured to be representative of the population. The remaining models in Table 30 were not acceptable because of excessive delay times in the Flash and Immediate precedences. As mentioned above, this was not caused by general saturation, but rather by an increase in waiting times experienced by the concentration of each of the higher precedences.

3. Table 31, Appendix E, lists those models with transit times in excess of the criterion when C was increased to 0.4. All but a very few of the models were unacceptable at this level. Those that did not meet the specifications fell into two categories:

a. The experiment was rejected because, as shown above, the sample was not representative.

b. The precedences were evenly distributed, i.e., the values of F, I, P, R were approximately equal.

Those that did not meet the specifications also fell into two categories:

a. Service 5 was saturated, or approaching saturation, thereby causing congestion and excessive waiting times in Queue 5.

b. The concentration of Flash and Immediate messages was high;

hence, their waiting times were increased at each facility.

Experiment 3

Experiment 3, the analysis of variance experiment mentioned in the preceding chapter, was designed to test the significance of varying the precedences and classifications. The results of the experiment are contained in Appendix B. Of particular interest here are the main effects, the percentage of the precedences, the precedences, the percentage of classification and the classification. Each main effect was found to be significant. The inference can be drawn that by varying any one of these in the input to the system some significant effect will be realized in the output. It should be noted here that although the effect of PM_i (precedence mix) is significant, its effect is small compared to P_j, C_k, and CM_l.

Experiment 4

Experiment 4 was conducted to determine if there is any correspondence between the input and the cumulative probability distribution of the transit times of the messages through the system. Two theoretical distribution functions were used to model the transit times.

Log-normal

The log-normal distribution produced unsatisfactory results. When testing the hypothesis that the distribution of the transit times were log-normal, the hypothesis was rejected because the confidence limits (level of significance, 0.05) was exceeded in every case tested. The goodness of fit test used in testing the hypothesis was the Kolmogorov-Smirnov or "d-test" (2, p. 168).

Weibull

The results using the Weibull distribution function,

$$F(t) = 1 - e^{-t^{\beta}/\alpha}$$

where α is the scale parameter, and β the shape parameter (2, p. 162), were more rewarding (Appendix C).

To obtain estimates of α and β Weibull probability paper was used. The procedure for making these estimates is contained in (28). Since the observed data were not in the form required for the use of Weibull probability paper, it was necessary to calculate corrected plotting positions (40). If we let:

t_i = corrected plotting time

n_i = number of messages in the time interval

t_i = time of readout

t_{i-1} = time of previous readout

then

$$t_i = \frac{n_i T_i + T_{i-1}}{n_i + 1}$$

To better linearize the Weibull plot a correction factor, $\hat{\gamma}$, was computed where $\hat{\gamma} = \hat{t}_1$. Each t_i was then adjusted by subtracting $\hat{\gamma}$ where $\hat{t}_i = t_i - \hat{t}_1$. The corrected data are plotted and, if the hypothesis is true, they should approximate a straight line. The characteristics of the line contain the information necessary to estimate α and β. Its intersection with the principal ordinate is $\ln \alpha$ (natural logarithm of α) and its slope is β.

To test the hypothesis that the data was distributed according to the Weibull distribution, a computer program for the Burroughs 220 system was written (Appendix D) where again the Kolmogorov-Smirnov goodness of fit test was used with a level of significance of 0.05. In every case tested the hypothesis was not rejected.

It was not the primary objective of this thesis to construct a predictive model. This was done only to investigate the feasibility of a general model to predict output, given the values of the parameters in the input. There is not much difference between the values of α and β in the first eight models where C and r are constant and P is varied; in fact, in five of those models the α and β values are identical. In the remaining models both C and r were varied and P was held constant. The change in α and β appears to be caused by the change in the values of C rather than r. This substantiates the results of the first experiment where the mean transit times were compared for different values of r and C, and it was found that some change resulted for different values of r; however, the primary significance was noted between the values of C.

Experiment 5

Experiment 5 was constructed to eliminate the congestion at Service 5 by increasing the number of tape cutting facilities. The experiment was conducted under the conditions noted in the preceding chapter. The results are contained in Tables 33 through 41 in Appendix

E. When there are two classified tape facilities in the system and when C = 0.3, the system is acceptable until E(t) approaches 120 seconds. At that time, not only do the classified tape facilities become saturated, but also the unclassified tape facilities (3 and 4). When C is increased to 0.6, the system becomes saturated at E(t) = 240 seconds; and as C is further increased to 0.9, the system is unacceptable at E(t) = 360 seconds. The system does not reach operational effectiveness through the installation of an additional facility (total of three) when C = 0.3. In this case, it would be necessary to add another unclassified unit. When C is increased to 0.6, saturation is reached as E(t) approaches 120 seconds. This is a reduction of 2 minutes in the interarrival times of the two-facility situation above. When C = 0.9, the system is acceptable until E(t) approaches 300 seconds. With a total of four classified tape facilities, the system becomes saturated at: E(t) = 120 seconds for C = 0.3; E(t) seconds for C = 0.06; and E(t) = 180 seconds for C = 0.9.

The capability of the system to effectively process messages under the above conditions is attained through the addition of more classified tape facilities. Another experiment was conducted along these same lines to determine the effect of using a floating facility, i.e., a facility that could be used for both classified and unclassified message traffic. This is not feasible in practice because the two facilities are normally located in separate areas of the Communication Center, and the movement of equipment back and forth between them is not practical. The results of the experiment were interesting, however, in that C was increased to 0.6 (when $E(t) = 360$ seconds) before the system became saturated. Though this is not as good as the addition of another facility, it would represent a savings in equipment. If the situation were to arise where the unclassified and classified processing units were housed in the same enclosure,* this would be a definite advantage, particularly where equipment shortages exist.

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*The placement of unclassified and classified facilities in the same area is not desirable due to the increased probability of processing a classified message through the unclassified unit.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Introduction

In the preceding chapters, each experiment was designed to test the effects of varying one or more of the parameter values on the transit times of the various types of messages.

In Experiment 1, it was found that as the percentage of classified messages (C) approached 40, the system became saturated due to the increased waiting time for classified Routine messages at Service 5. It was also found that by varying the shape parameter (r) of the distribution of the interarrival times of incoming messages, the resulting transit times were not affected to the extent they were when C was varied.

Experiment 2 showed that as the percentage of Flash and Immediate messages was increased, the system became saturated due to increased waiting times caused by the high concentration of these messages in the system. It was also found that as C was increased from 0.2 to 0.3 the combination of $F + I > 0.70$ caused the system to be saturated because of excessive delay times for Flash and Immediate messages. When $C = 0.2$ only Flash messages were affected and then only when $F \geq 0.80$. When C was increased to 0.4, almost all models in the experiment were found to be unacceptable. The only exception was where F, I, P, and R were evenly distributed. It was also noted that generally the reason for excessive delay times for Priority and Routine messages was caused by the saturation of Service 5 (100 per cent utilization), whereas it was due to the high density of Flash and Immediate messages when these two precedences were the cause for non-acceptability.

Experiment 3 showed that the effect of varying precedence mix or classification mix is significant at a significance level of 5 per cent.

Though Experiment 4 provided no conclusive evidence on the existence of a general distribution function for transit times, it did substantiate previous experiments by showing that the parameters of the distributions were different when C was varied.

By increasing the number of classified tape cutting facilities, it was found in Experiment 5 that for a particular value of r and P, the values of C could be increased considerably before saturation developed due to an increase of messages in the system.

With these observations, certain conclusions can be made regarding the assignment of personnel and equipment to a particular detail.

Conclusions

1. The standard authorization of personnel and equipment (the basic model) can effectively process messages if the value of the parameters are within the ranges specified in Table 4.

2. With the addition of one classified tape cutting facility, the system can effectively process messages if the parameters are within the values specified in Table 5.

3. With the addition of two classified tape cutting facilities, the system can effectively process messages if the parameters are within

Table 4. Limitations on Parameters for the Basic Model

E(t)	r	C	F	I	Pr	R
≥360	≥1	≤0.2	≤0.8	NR*	NR	NR
≥360	≥1	≤0.3	F+I≤0.65		Pr+R≤0.85	
≥360	≥1	≤0.4	0.25±0.10	0.25±0.10	0.25±0.10	0.25±0.10

*No restriction.

Table 5. Limitations on Parameters with the Addition of One Classified Tape Cutting Facility

E(t)	r	C
300 ≤ E(t) ≤ 360	≥ 1	≤ 0.60
180 ≤ E(t) ≤ 360	≥ 1	≤ 0.30
> 360	≥ 1	≤ 0.90

the values specified in Table 6.

4. With the addition of three classified tape cutting facilities the system can effectively process messages if the parameters are within the values specified in Table 7.

With these tables the Army Signal Officer can make definite statements about the ability of a message center to function effectively under given conditions.

Recommendations

If portions of this topic are considered for further study, the researcher should try to avoid the following pitfalls that were encountered in this thesis:

1. When employing GPSS III, use the smallest time units (within limits) available for the random variable under consideration. In this thesis, in actuality, Experiment 2 was conducted prior to Experiment 1, and minutes were used for the time units of the random variable time. After Experiment 2 was completed, it was found that the GENERATE block truncated the interarrival times to the lowest integer, i.e., rounds down. The time between arrivals is then lower than it should be by a maximum of 0.999 minutes. This obviously reduces the accuracy of the experiment particularly when E(t) is relatively small (less than ten minutes). In Experiment 1, and all experiments conducted after Experiment 2, seconds were used and this effect was largely eliminated.

2. The error produced by the failure to process low precedence messages as the system approaches saturation was compensated for in this study by disregarding the data completely. Further investigation of

Table 6. Limitations on Parameters with the Addition of Two Classified Tape Cutting Facilities

E(t)	r	C
$180 \leq E(t) \leq 360$	≥ 1	≤ 0.3
$180 \leq E(t) \leq 360$	≥ 1	≤ 0.60
≥ 360	≥ 1	≤ 0.90

Table 7. Limitations on Parameters with the Addition of Three Classified Tape Cutting Facilities

E(t)	r	C
$180 \leq E(t) \leq 360$	≥ 1	≤ 0.30
$180 \leq E(t) \leq 360$	≥ 1	≤ 0.60
$240 \leq E(t) \leq 360$	≥ 1	≤ 0.90

this problem is recommended.

3. Where computer time is critical, GPSS III is limited in application. The total computer time required on the IBM 7094 for the completion of Experiment 1, for example, was approximately 450 minutes or 7.5 hours. This is running time. It does not include set-up or input-output time.

The assumption was made in conducting this research that all teletypewriter systems were full-duplex, i.e., can transmit and receive messages simultaneously. Though this assumption would not appreciably affect the operation of a message center as small as the one studied here, it would have a decided effect on a larger message center where a teletypewriter switching central* is employed. If such a study were undertaken, the input to the central could be determined from the output of the model used in this research by tabulating the time between termination of messages rather than transit times.

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*A teletypewriter switching central is a switchboard used for routine teletype traffic. All circuits entering the central must be half-duplex, i.e., transmit or receive, but not simultaneously.

APPENDIX

APPENDIX A

GPSS III PROGRAM

AND INITIAL COMPUTER RUN

```
                                  GPSS III ASSEMBLY INPUT                                 PAGE 1

BLOCK
NUMBER     *LOC    NAME        A,B,C,D,E                        COMMENTS

            *      SIMULATE
            *      BEGINNING OF MODEL 10
                 1 FUNCTION    RN1,C24       EXPONENTIAL DISTRIBUTION FOR ARRIVALS
           0      0      .1    .104   .2     .222  .3    .355  .4    .509  .5    .69
           .6     .915   .7    1.2    .75    1.38  .8    1.6   .84   1.83  .88   2.12
           .9     2.3    .92   2.52   .94    2.81  .95   2.99  .96   3.2   .97
           .98    3.9    .99   4.6    .995   5.3   .998  6.2   .999  7     .9997 8
                 2 FUNCTION    RN1,D4        DISTRIBUTION FOR PRECEDENCES
           .05    4      .15   3      .5     2     1.0   1
                 3 FUNCTION    Q2,D2         MEAN TIME FOR SERVICE 2
           7      3      1000  2
                 4 FUNCTION    Q3,D5         MEAN TIME FOR SERVICE 3
           8      8      9     7      10     6     11    5     1000  4
                 5 FUNCTION    RN1,D2        MESSAGE CLASSIFICATION
           .8     1      1.0   2
                 6 FUNCTION    RN1,D3        MESSAGE DESTINATION
           .4     39     .7    45     1      51
                 7 FUNCTION    RN1,D2        MESSAGE CLASSIFICATION FOR FLASH
           .95    1      1.0   2
   1               GENERATE    6,FN1         CREATE INCOMING MESSAGES
   2               QUEUE       1,1           JOIN QUEUE 1 TO AWAIT SERVICE
   3               SEIZE       1             GET SERVICE 1
   4               DEPART      1,1           DEPART FROM QUEUE 1
   5               ADVANCE     1,FN1         SERVICE 1
   6               ASSIGN      3,FN2         ASSIGN PRECEDENCES TO PARAMETER 3
   7               PRIORITY    P3            ASSIGN PRECEDENCES
   8               RELEASE     1             RELEASE SERVICE 1
   9               QUEUE       2,1           JOIN QUEUE 2 TO AWAIT SERVICE
  10               PREEMPT     2             INTERRUPT LOWER PRIORITY MESSAGES
  11               DEPART      2,1           DEPART FROM QUEUE 2
  12               ADVANCE     FN3,FN1       SERVICE 2
  13               TEST GE     P3,K4,ASGNC   SEND FLASH TO CLASSIFICATION ASSIGNMENT
  14               ASSIGN      1,FN7         ASSIGN CLASSIFICATION TO FLASH
  15               TRANSFER    ,ASGND        SEND FLASH TO DESTINATION ASSIGNMENT
  16       ASGNC   ASSIGN      1,FN5         ASSIGN CLASSIFICATION TO OTHERS
  17       ASGND   ASSIGN      2,FN6         ASSIGN DESTINATION
  18               RETURN      2             LEAVE SERVICE 2
  19               TEST NE     P1,K2,CLAS    SEPARATE BY CLASSIFICATION
  20               TEST GE     Q4,Q3,OTHER   SEND TO Q4 IF Q3 GREATER THAN Q4
  21               QUEUE       3             JOIN QUEUE 3
  22               PREEMPT     3             INTERRUPT LOWER PRIORITY MESSAGES
  23               DEPART      3,1           DEPART FROM QUEUE 3
  24               ADVANCE     FN4,FN1       SERVICE 3
  25               RETURN      3             LEAVE SERVICE 3
  26               TRANSFER    ,*2           SEND TO XMITTING POINT PER PARAMETER 2
  27       OTHER   QUEUE       4             JOIN QUEUE 3 TO AWAIT SERVICE
  28               PREEMPT     4             INTERRUPT LOWER PRIORITY MESSAGES
  29               DEPART      4,1           DEPART FROM QUEUE 4
  30               ADVANCE     FN4,FN1       SERVICE 4
  31               RETURN      4             LEAVE SERVICE 4
  32               TRANSFER    ,*2           SEND TO XMITTING POINT PER PARAMETER 2
  33       CLAS    QUEUE       5             JOIN QUEUE 5 TO AWAIT SERVICE
  34               PREEMPT     5             INTERRUPT LOWER PRIORITY MESSAGES
  35               DEPART      5,1           DEPART FROM QUEUE 5

  36               ADVANCE     20,FN1        SERVICE 5
  37               RETURN      5             LEAVE SERVICE 5
  38               TRANSFER    ,*2           SEND TO XMITTING POINT PER PARAMETER 2
  39               QUEUE       6,1           JOIN QUEUE 6
  40               PREEMPT     6             INTERRUPT LOWER PRIORITY MESSAGES
  41               DEPART      6,1           DEPART FROM QUEUE 6
  42               ADVANCE     6,FN1         SERVICE 6
  43               RETURN      6             LEAVE SERVICE 6
  44               TRANSFER    ,TAB1         SEND TO TABULATE
  45               QUEUE       7,1           JOIN QUEUE 7 TO AWAIT SERVICE
  46               PREEMPT     7             INTERRUPT LOWER PRIORITY MESSAGES
  47               DEPART      7,1           DEPART FROM QUEUE 7
  48               ADVANCE     6,FN1         SERVICE 7
  49               RETURN      7             LEAVE SERVICE 7
  50               TRANSFER    ,TAB1         SEND TO TABULATE
  51               QUEUE       8             JOIN QUEUE 8 TO AWAIT SERVICE
  52               PREEMPT     8             INTERRUPT LOWER PRIORITY MESSAGES
  53               DEPART      8             DEPART FROM QUEUE 8
  54               ADVANCE     6,FN1         SERVICE 8
  55               RETURN      8             LEAVE SERVICE 8
  56               TRANSFER    ,TAB1         SEND TO TABULATE
  57       TAB1    TEST NE     P3,K4,FLASH   SEPARATE FLASH MESSAGES
  58               TEST NE     P3,K3,IMMED   SEPARATE IMMEDIATE MESSAGES
  59               TEST NE     P3,K2,PRIOR   SEPARATE PRIORITY MESSAGES
  60               TEST NE     P3,K1,ROUTE   SEPARATE ROUTINE MESSAGES
  61       FLASH   TEST NE     P1,K2,TABCF   SEPARATE FLASH CLASSIFIED
  62               TABULATE    1             TABULATE UNCLASSIFIED FLASH
  63               TRANSFER    ,TABF         SEND TO TABULATE TOTAL FLASH
  64       TABCF   TABULATE    2             TABULATE CLASSIFIED FLASH
  65       TABF    TABULATE    3             TABULATE TOTAL FLASH
  66               TRANSFER    ,TABT         SEND TO TABULATE TOTAL
  67       IMMED   TEST NE     P1,K2,TABCI   SEPARATE IMMEDIATE CLASSIFIED
  68               TABULATE    4             TABULATE UNCLASSIFIED IMMEDIATE
  69               TRANSFER    ,TAB1         SEND TO TABULATE TOTAL IMMEDIATE
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70        TABCI TABULATE   5            TABULATE CLASSIFIED IMMEDIATE
71        TABI  TABULATE   6            TABULATE TOTAL IMMEDIATE
72              TRANSFER   ,TABT        SEND TO TABULATE TOTAL
73        PRICR TEST NE    P1,K2,TABCP  SEPARATE PRIORITY CLASSIFIED
74              TABULATE   7            TABULATE UNCLASSIFIED PRIORITY
75              TRANSFER   ,TABP        SEND TO TABULATE TOTAL PRIORITY
76        TABCP TABULATE   8            TABULATE CLASSIFIED PRIORITY
77        TABP  TABULATE   9            TABULATE TOTAL PRIORITY
78              TRANSFER   ,TABT        SEND TO TABULATE TOTAL
79        ROUTE TEST NE    P1,K2,TABCR  SEPARATE ROUTINE CLASSIFIED
80              TABULATE   10           TABULATE UNCLASSIFIED ROUTINE
81              TRANSFER   ,TABR        SEND TO TABULATE TOTAL ROUTINE
82        TABCR TABULATE   11           TABULATE CLASSIFIED ROUTINE
83        TABR  TABULATE   12           TABULATE TOTAL ROUTINE
84        TABT  TABULATE   13           TABULATE TOTAL
85              TERMINATE  1            REMOVE MESSAGE FROM SYSTEM
              1 TABLE      M1,0,5,302
              2 TABLE      M1,0,5,302
              3 TABLE      M1,0,5,302
              4 TABLE      M1,0,5,302
              5 TABLE      M1,0,5,302
              6 TABLE      M1,0,5,302
              7 TABLE      M1,0,5,302
              8 TABLE      M1,0,5,302
              9 TABLE      M1,0,5,302
             10 TABLE      M1,0,5,302
             11 TABLE      M1,0,5,302
             12 TABLE      M1,0,5,302
             13 TABLE      M1,0,5,302
                START      200          TRANSIENT RUN
                RESET
                START      1000         PRODUCTION RUN
```

CLOCK TIME 5490 6691

BLOCK COUNTS	BLOCK	TRANS,TOTAL	BLOCK	TRANS,TOTAL	BLOCK	TRANS,TOTAL	BLOCK	TRANS,TOTAL	BLOCK	TRANS,TOTAL
	1	0, 1009	2	0, 1009	3	0, 1009	4	0, 1009	5	0, 1009
	6	0, 1009	7	0, 1009	8	0, 1009	9	0, 1009	10	0, 1009
	11	0, 1009	12	0, 1009	13	0, 1010	14	0, 55	15	0, 55
	16	0, 955	17	0, 1010	18	0, 1010	19	0, 1010	20	0, 810
	21	4, 521	22	0, 518	23	0, 518	24	1, 518	25	0, 518
	26	0, 518	27	4, 289	28	0, 285	29	0, 285	30	1, 285
	31	0, 284	32	0, 284	33	2, 200	34	0, 199	35	0, 199
	36	1, 199	37	0, 199	38	0, 199	39	1, 385	40	0, 384
	41	0, 384	42	0, 384	43	0, 384	44	0, 384	45	0, 295
	46	0, 295	47	0, 295	48	0, 295	49	0, 295	50	0, 295
	51	0, 321	52	0, 322	53	0, 322	54	1, 322	55	0, 321
	56	0, 321	57	0, 1000	58	0, 947	59	0, 850	60	0, 517
	61	0, 53	62	0, 52	63	0, 52	64	0, 1	65	0, 53
	66	0, 53	67	0, 97	68	0, 80	69	0, 80	70	0, 17
	71	0, 97	72	0, 97	73	0, 333	74	0, 263	75	0, 263
	76	0, 70	77	0, 333	78	0, 333	79	0, 517	80	0, 407
	81	0, 407	82	0, 110	83	0, 517	84	0, 1000	85	0, 1000

FACILITY NUMBER	AVERAGE UTILIZATION	NUMBER ENTRIES	AVERAGE TIME/TRANS	SEIZING TRANS. NO.	PREMPTING TRANS. NO.
1	.1018	1009	.55	0	0
2	.4570	1010	2.48	0	0
3	.7168	519	7.58	0	17
4	.3710	285	7.15	0	11
5	.7058	200	19.38	0	12
6	.3876	384	5.54	0	0
7	.2954	295	5.50	0	0
8	.3293	322	5.61	0	8

QUEUE NUMBER	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/TRANS	$AVERAGE TIME/TRANS	TABLE NUMBER	CURRENT CONTENTS
1	3	.04	1009	905	89.7	.19	1.86	0	0
2	10	.49	1009	563	55.8	2.64	5.98	0	0
3	6	.66	522	223	42.7	6.93	12.10	0	4
4	6	.28	289	148	51.2	5.34	10.94	0	4
5	14	2.05	201	54	26.9	56.10	76.71	0	2
6	6	.22	385	236	61.3	3.12	8.07	0	1
7	5	.18	295	208	70.5	3.26	11.07	0	0
8	8	.29	322	208	64.6	5.01	14.15	0	0

$AVERAGE TIME/TRANS = AVERAGE TIME/TRANS EXCLUDING ZERO ENTRIES

TABLE NUMBER 1

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
52	22.923	11.547	1192.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	1	1.92	1.9	98.1	.000	-1.985
5	1	1.92	3.8	96.2	.218	-1.552
10	3	5.77	9.6	90.4	.436	-1.119
15	9	17.31	26.9	73.1	.654	-.686
20	10	19.23	46.2	53.8	.872	-.253
25	10	19.23	65.4	34.6	1.091	.180
30	5	9.62	75.0	25.0	1.309	.613
35	8	15.38	90.4	9.6	1.527	1.046
40	1	1.92	92.3	7.7	1.745	1.479
45	1	1.92	94.2	5.8	1.963	1.912
50	1	1.92	96.2	3.8	2.181	2.345
55	1	1.92	98.1	1.9	2.399	2.778
60	1	1.92	100.0	.0	2.617	3.211

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 2

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
1	43.000	.000	43.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	.000	-.000
5	0	.00	.0	100.0	.116	-.000
10	0	.00	.0	100.0	.233	-.000
15	0	.00	.0	100.0	.349	-.000
20	0	.00	.0	100.0	.465	-.000
25	0	.00	.0	100.0	.581	-.000
30	0	.00	.0	100.0	.698	-.000
35	0	.00	.0	100.0	.814	-.000
40	0	.00	.0	100.0	.930	-.000
45	1	100.00	100.0	.0	1.047	.000

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 3

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
53	23.302	11.763	1235.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	1	1.89	1.9	98.1	.000	-1.981
5	1	1.89	3.8	96.2	.215	-1.556
10	3	5.66	9.4	90.6	.429	-1.131
15	9	16.98	26.4	73.6	.644	-.706
20	10	18.87	45.3	54.7	.858	-.281
25	10	18.87	64.2	35.8	1.073	.144
30	5	9.43	73.6	26.4	1.287	.569
35	8	15.09	88.7	11.3	1.502	.994
40	1	1.89	90.6	9.4	1.717	1.420
45	2	3.77	94.3	5.7	1.931	1.845
50	1	1.89	96.2	3.8	2.146	2.270
55	1	1.89	98.1	1.9	2.360	2.695
60	1	1.89	100.0	.0	2.575	3.120

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 4

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
80	28.500	15.949	2280.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	.000	-1.787
5	1	1.25	1.2	98.8	.175	-1.473
10	3	3.75	5.0	95.0	.351	-1.160
15	12	15.00	20.0	80.0	.526	-.846
20	15	18.75	38.7	61.3	.702	-.533
25	8	10.00	48.7	51.3	.877	-.219
30	10	12.50	61.2	38.8	1.053	.094
35	9	11.25	72.5	27.5	1.228	.408
40	4	5.00	77.5	22.5	1.404	.721
45	8	10.00	87.5	12.5	1.579	1.035
50	5	6.25	93.7	6.3	1.754	1.348
55	1	1.25	95.0	5.0	1.930	1.662
60	0	.00	95.0	5.0	2.105	1.975
65	1	1.25	96.2	3.8	2.281	2.289
70	0	.00	96.2	3.8	2.456	2.602
75	0	.00	96.2	3.8	2.632	2.915
80	2	2.50	98.7	1.3	2.807	3.229
85	1	1.25	100.0	.0	2.982	3.542

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 5

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
17	47.941	23.107	815.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	.000	-2.075
5	0	.00	.0	100.0	.104	-1.858
10	1	5.88	5.9	94.1	.209	-1.642
15	0	.00	5.9	94.1	.313	-1.426
20	1	5.88	11.8	88.2	.417	-1.209
25	1	5.88	17.6	82.4	.521	-.993
30	0	.00	17.6	82.4	.626	-.776
35	2	11.76	29.4	70.6	.730	-.560
40	1	5.88	35.3	64.7	.834	-.344
45	2	11.76	47.1	52.9	.939	-.127
50	1	5.88	52.9	47.1	1.043	.089
55	2	11.76	64.7	35.3	1.147	.305
60	3	17.65	82.4	17.6	1.252	.522
65	0	.00	82.4	17.6	1.356	.738
70	1	5.88	88.2	11.8	1.460	.955
75	0	.00	88.2	11.8	1.564	1.171
80	0	.00	88.2	11.8	1.669	1.387
85	1	5.88	94.1	5.9	1.773	1.604
90	0	.00	94.1	5.9	1.877	1.820
95	0	.00	94.1	5.9	1.982	2.037
100	1	5.88	100.0	.0	2.086	2.253

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 6

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
97	31.907	18.802	3095.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	.000	-1.697
5	1	1.03	1.0	99.0	.157	-1.431
10	4	4.12	5.2	94.8	.313	-1.165
15	12	12.37	17.5	82.5	.470	-.899
20	16	16.49	34.0	66.0	.627	-.633
25	9	9.28	43.3	56.7	.784	-.367
30	10	10.31	53.6	46.4	.940	-.101
35	11	11.34	64.9	35.1	1.097	.164
40	5	5.15	70.1	29.9	1.254	.430
45	10	10.31	80.4	19.6	1.410	.696
50	6	6.19	86.6	13.4	1.567	.962
55	3	3.09	89.7	10.3	1.724	1.228
60	3	3.09	92.8	7.2	1.880	1.494
65	1	1.03	93.8	6.2	2.037	1.760
70	1	1.03	94.8	5.2	2.194	2.026
75	0	.00	94.8	5.2	2.351	2.292
80	2	2.06	96.9	3.1	2.507	2.558
85	2	2.06	99.0	1.0	2.664	2.824
90	0	.00	99.0	1.0	2.821	3.090
95	0	.00	99.0	1.0	2.977	3.356
100	1	1.03	100.0	.0	3.134	3.622

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 7

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
263	26.973	17.052	7094.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	1	.38	.4	99.6	.000	-1.582
5	7	2.66	3.0	97.0	.185	-1.289
10	25	9.51	12.5	87.5	.371	-.995
15	41	15.59	28.1	71.9	.556	-.702
20	46	17.49	45.6	54.4	.741	-.409
25	26	9.89	55.5	44.5	.927	-.116
30	20	7.60	63.1	36.9	1.112	.177
35	30	11.41	74.5	25.5	1.298	.471
40	16	6.08	80.6	19.4	1.483	.764
45	17	6.46	87.1	12.9	1.668	1.057
50	11	4.18	91.3	8.7	1.854	1.350
55	6	2.28	93.5	6.5	2.039	1.644
60	7	2.66	96.2	3.8	2.224	1.937
65	2	.76	97.0	3.0	2.410	2.230
70	4	1.52	98.5	1.5	2.595	2.523
75	1	.38	98.9	1.1	2.781	2.817
80	1	.38	99.2	.8	2.966	3.110
85	0	.00	99.2	.8	3.151	3.403
90	0	.00	99.2	.8	3.337	3.696
95	0	.00	99.2	.8	3.522	3.989
100	0	.00	99.2	.8	3.707	4.283
105	1	.38	99.6	.4	3.893	4.576
110	0	.00	99.6	.4	4.078	4.869
115	1	.38	100.0	.0	4.263	5.162

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 8

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
70	56.186	35.950	3933.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	.000	-1.563
5	2	2.86	2.9	97.1	.089	-1.424
10	1	1.43	4.3	95.7	.178	-1.285
15	3	4.29	8.6	91.4	.267	-1.146
20	2	2.86	11.4	88.6	.356	-1.007
25	4	5.71	17.1	82.9	.445	-.867
30	6	8.57	25.7	74.3	.534	-.728
35	6	8.57	34.3	65.7	.623	-.589
40	5	7.14	41.4	58.6	.712	-.450
45	5	7.14	48.6	51.4	.801	-.311
50	3	4.29	52.9	47.1	.890	-.172
55	5	7.14	60.0	40.0	.979	-.033
60	3	4.29	64.3	35.7	1.068	.106
65	4	5.71	70.0	30.0	1.157	.245
70	2	2.86	72.9	27.1	1.246	.384
75	3	4.29	77.1	22.9	1.335	.523
80	2	2.86	80.0	20.0	1.424	.662
85	1	1.43	81.4	18.6	1.513	.802
90	1	1.43	82.9	17.1	1.602	.941
95	1	1.43	84.3	15.7	1.691	1.080
100	0	.00	84.3	15.7	1.780	1.219
105	0	.00	84.3	15.7	1.869	1.358
110	2	2.86	87.1	12.9	1.958	1.497
115	2	2.86	90.0	10.0	2.047	1.636
120	2	2.86	92.9	7.1	2.136	1.775
125	1	1.43	94.3	5.7	2.225	1.914
130	0	.00	94.3	5.7	2.314	2.053
135	2	2.86	97.1	2.9	2.403	2.192
140	1	1.43	98.6	1.4	2.492	2.331
145	0	.00	98.6	1.4	2.581	2.470
150	0	.00	98.6	1.4	2.670	2.610
155	1	1.43	100.0	.0	2.759	2.749

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 9

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
333	33.114	25.302	11027.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	1	.30	.3	99.7	.000	-1.309
5	9	2.70	3.0	97.0	.151	-1.111
10	26	7.81	10.8	89.2	.302	-.914
15	44	13.21	24.0	76.0	.453	-.716
20	48	14.41	38.4	61.6	.604	-.518
25	30	9.01	47.4	52.6	.755	-.321
30	26	7.81	55.3	44.7	.906	-.123
35	36	10.81	66.1	33.9	1.057	.075
40	21	6.31	72.4	27.6	1.208	.272
45	22	6.61	79.0	21.0	1.359	.470
50	14	4.20	83.2	16.8	1.510	.667
55	11	3.30	86.5	13.5	1.661	.865
60	10	3.00	89.5	10.5	1.812	1.063
65	6	1.80	91.3	8.7	1.963	1.260
70	6	1.80	93.1	6.9	2.114	1.458
75	4	1.20	94.3	5.7	2.265	1.655
80	3	.90	95.2	4.8	2.416	1.853
85	1	.30	95.5	4.5	2.567	2.051
90	1	.30	95.8	4.2	2.718	2.248
95	1	.30	96.1	3.9	2.869	2.446
100	0	.00	96.1	3.9	3.020	2.644
105	1	.30	96.4	3.6	3.171	2.841
110	2	.60	97.0	3.0	3.322	3.039
115	3	.90	97.9	2.1	3.473	3.236
120	2	.60	98.5	1.5	3.624	3.434
125	1	.30	98.8	1.2	3.775	3.632
130	0	.00	98.8	1.2	3.926	3.829
135	2	.60	99.4	.6	4.077	4.027
140	1	.30	99.7	.3	4.228	4.224
145	0	.00	99.7	.3	4.379	4.422
150	0	.00	99.7	.3	4.530	4.620
155	1	.30	100.0	.0	4.681	4.817

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 10

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
407	30.909	19.888	12580.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	.000	-1.554
5	21	5.16	5.2	94.8	.162	-1.303
10	17	4.18	9.3	90.7	.324	-1.051
15	41	10.07	19.4	80.6	.485	-.800
20	64	15.72	35.1	64.9	.647	-.549
25	57	14.00	49.1	50.9	.809	-.297
30	46	11.30	60.4	39.6	.971	-.046
35	29	7.13	67.6	32.4	1.132	.206
40	30	7.37	74.9	25.1	1.294	.457
45	29	7.13	82.1	17.9	1.456	.709
50	13	3.19	85.3	14.7	1.618	.960
55	12	2.95	88.2	11.8	1.779	1.211
60	8	1.97	90.2	9.8	1.941	1.463
65	9	2.21	92.4	7.6	2.103	1.714
70	11	2.70	95.1	4.9	2.265	1.966
75	5	1.23	96.3	3.7	2.426	2.217
80	6	1.47	97.8	2.2	2.588	2.468
85	3	.74	98.5	1.5	2.750	2.720
90	2	.49	99.0	1.0	2.912	2.971
95	1	.25	99.3	.7	3.074	3.223
100	0	.00	99.3	.7	3.235	3.474
105	1	.25	99.5	.5	3.397	3.725
110	0	.00	99.5	.5	3.559	3.977
115	1	.25	99.8	.2	3.721	4.228
120	0	.00	99.8	.2	3.882	4.480
125	0	.00	99.8	.2	4.044	4.731
130	0	.00	99.8	.2	4.206	4.982
135	0	.00	99.8	.2	4.368	5.234
140	1	.25	100.0	.0	4.529	5.485

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 11

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
110	120.645	59.705	13271.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMLLATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	.000	-1.210
5	2	1.82	1.8	98.2	.041	-1.160
10	1	.91	2.7	97.3	.083	-1.110
15	3	2.73	5.5	94.5	.124	-1.060
20	7	6.36	11.8	88.2	.166	-1.009
25	4	3.64	15.5	84.5	.207	-.959
30	5	4.55	20.0	80.0	.249	-.909
35	4	3.64	23.6	76.4	.290	-.859
40	0	.00	23.6	76.4	.332	-.809
45	3	2.73	26.4	73.6	.373	-.759
50	3	2.73	29.1	70.9	.414	-.709
55	3	2.73	31.8	68.2	.456	-.658
60	5	4.55	36.4	63.6	.497	-.608
65	4	3.64	40.0	60.0	.539	-.558
70	3	2.73	42.7	57.3	.580	-.508
75	9	8.18	50.9	49.1	.622	-.458
80	2	1.82	52.7	47.3	.663	-.408
85	1	.91	53.6	46.4	.705	-.358
90	1	.91	54.5	45.5	.746	-.307
95	2	1.82	56.4	43.6	.787	-.257
100	0	.00	56.4	43.6	.829	-.207
105	0	.00	56.4	43.6	.870	-.157
110	2	1.82	58.2	41.8	.912	-.107
115	2	1.82	60.0	40.0	.953	-.057
120	1	.91	60.9	39.1	.995	-.006
125	2	1.82	62.7	37.3	1.036	.044
130	0	.00	62.7	37.3	1.078	.094
135	1	.91	63.6	36.4	1.119	.144
140	1	.91	64.5	35.5	1.160	.194
145	3	2.73	67.3	32.7	1.202	.244
150	1	.91	68.2	31.8	1.243	.294
155	1	.91	69.1	30.9	1.285	.345
160	1	.91	70.0	30.0	1.326	.395
165	2	1.82	71.8	28.2	1.368	.445
170	1	.91	72.7	27.3	1.409	.495
175	0	.00	72.7	27.3	1.451	.545
180	1	.91	73.6	26.4	1.492	.595
185	1	.91	74.5	25.5	1.533	.645
190	0	.00	74.5	25.5	1.575	.696
195	0	.00	74.5	25.5	1.616	.746
200	0	.00	74.5	25.5	1.658	.796
205	1	.91	75.5	24.5	1.699	.846
210	1	.91	76.4	23.6	1.741	.896
215	0	.00	76.4	23.6	1.782	.946
220	0	.00	76.4	23.6	1.824	.996
225	0	.00	76.4	23.6	1.865	1.047
230	0	.00	76.4	23.6	1.906	1.097
235	4	3.64	80.0	20.0	1.948	1.147
240	1	.91	80.9	19.1	1.989	1.197
245	2	1.82	82.7	17.3	2.031	1.247
250	3	2.73	85.5	14.5	2.072	1.297
255	3	2.73	88.2	11.8	2.114	1.348
260	0	.00	88.2	11.8	2.155	1.398
265	0	.00	88.2	11.8	2.197	1.448
270	0	.00	88.2	11.8	2.238	1.498
275	2	1.82	90.0	10.0	2.279	1.548
280	3	2.73	92.7	7.3	2.321	1.598
285	2	1.82	94.5	5.5	2.362	1.648
290	0	.00	94.5	5.5	2.404	1.699
295	1	.91	95.5	4.5	2.445	1.749
300	2	1.82	97.3	2.7	2.487	1.799
305	0	.00	97.3	2.7	2.528	1.849
310	0	.00	97.3	2.7	2.570	1.899
315	0	.00	97.3	2.7	2.611	1.949
320	0	.00	97.3	2.7	2.652	1.999
325	0	.00	97.3	2.7	2.694	2.050
330	0	.00	97.3	2.7	2.735	2.100
335	1	.91	98.2	1.8	2.777	2.150
340	0	.00	98.2	1.8	2.818	2.200
345	0	.00	98.2	1.8	2.860	2.250
350	0	.00	98.2	1.8	2.901	2.300
355	0	.00	98.2	1.8	2.943	2.350
360	0	.00	98.2	1.8	2.984	2.401
365	0	.00	98.2	1.8	3.025	2.451
370	0	.00	98.2	1.8	3.067	2.501
375	0	.00	98.2	1.8	3.108	2.551
380	0	.00	98.2	1.8	3.150	2.601
385	0	.00	98.2	1.8	3.191	2.651
390	0	.00	98.2	1.8	3.233	2.702
395	1	.91	99.1	.9	3.274	2.752
400	0	.00	99.1	.9	3.315	2.802
405	0	.00	99.1	.9	3.357	2.852
410	0	.00	99.1	.9	3.398	2.902
415	0	.00	99.1	.9	3.440	2.952
420	0	.00	99.1	.9	3.481	3.002
425	0	.00	99.1	.9	3.523	3.053
430	1	.91	100.0	.0	3.564	3.103

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 12

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
517	50.002	61.340	25851.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	.00C	-.815
5	23	4.45	4.4	95.6	.10C	-.734
10	18	3.48	7.9	92.1	.20C	-.652
15	44	8.51	16.4	83.6	.30C	-.571
20	71	13.73	30.2	69.8	.40C	-.489
25	61	11.80	42.0	58.0	.50C	-.408
30	51	9.86	51.8	48.2	.60C	-.326
35	33	6.38	58.2	41.8	.70C	-.245
40	30	5.80	64.0	36.0	.80C	-.163
45	32	6.19	70.2	29.8	.90C	-.082
50	16	3.09	73.3	26.7	1.00C	-.000
55	15	2.90	76.2	23.8	1.10C	.081
60	13	2.51	78.7	21.3	1.20C	.163
65	13	2.51	81.2	18.8	1.30C	.245
70	14	2.71	83.9	16.1	1.40C	.326
75	14	2.71	86.7	13.3	1.50C	.408
80	8	1.55	88.2	11.8	1.60C	.489
85	4	.77	89.0	11.0	1.70C	.571
90	3	.58	89.6	10.4	1.80C	.652
95	3	.58	90.1	9.9	1.90C	.734
100	0	.00	90.1	9.9	2.00C	.815
105	1	.19	90.3	9.7	2.10C	.897
110	2	.39	90.7	9.3	2.20C	.978
115	3	.58	91.3	8.7	2.30C	1.060
120	1	.19	91.5	8.5	2.40C	1.141
125	2	.39	91.9	8.1	2.50C	1.223
130	0	.00	91.9	8.1	2.60C	1.304
135	1	.19	92.1	7.9	2.70C	1.386
140	2	.39	92.5	7.5	2.80C	1.467
145	3	.58	93.0	7.0	2.90C	1.549
150	1	.19	93.2	6.8	3.00C	1.630
155	1	.19	93.4	6.6	3.10C	1.712
160	1	.19	93.6	6.4	3.20C	1.793
165	2	.39	94.0	6.0	3.30C	1.875
170	1	.19	94.2	5.8	3.40C	1.956
175	0	.00	94.2	5.8	3.50C	2.038
180	1	.19	94.4	5.6	3.60C	2.119
185	1	.19	94.6	5.4	3.70C	2.201
190	0	.00	94.6	5.4	3.80C	2.282
195	0	.00	94.6	5.4	3.90C	2.364
200	0	.00	94.6	5.4	4.00C	2.445
205	1	.19	94.8	5.2	4.10C	2.527
210	1	.19	95.0	5.0	4.20C	2.608
215	0	.00	95.0	5.0	4.30C	2.690
220	0	.00	95.0	5.0	4.40C	2.771
225	0	.00	95.0	5.0	4.50C	2.853
230	0	.00	95.0	5.0	4.60C	2.934
235	4	.77	95.7	4.3	4.70C	3.016
240	1	.19	95.9	4.1	4.80C	3.097
245	2	.39	96.3	3.7	4.90C	3.179
250	3	.58	96.9	3.1	5.00C	3.260
255	3	.58	97.5	2.5	5.10C	3.342
260	0	.00	97.5	2.5	5.20C	3.424
265	0	.00	97.5	2.5	5.30C	3.505
270	0	.00	97.5	2.5	5.40C	3.587
275	2	.39	97.9	2.1	5.50C	3.668
280	3	.58	98.5	1.5	5.60C	3.750
285	2	.39	98.8	1.2	5.70C	3.831
290	0	.00	98.8	1.2	5.80C	3.913
295	1	.19	99.0	1.0	5.90C	3.994
300	2	.39	99.4	.6	6.00C	4.076
305	0	.00	99.4	.6	6.10C	4.157
310	0	.00	99.4	.6	6.20C	4.239
315	0	.00	99.4	.6	6.30C	4.320
320	0	.00	99.4	.6	6.40C	4.402
325	0	.00	99.4	.6	6.50C	4.483
330	0	.00	99.4	.6	6.60C	4.565
335	1	.19	99.6	.4	6.70C	4.646
340	0	.00	99.6	.4	6.80C	4.728
345	0	.00	99.6	.4	6.90C	4.809
350	0	.00	99.6	.4	7.00C	4.891
355	0	.00	99.6	.4	7.10C	4.972
360	0	.00	99.6	.4	7.20C	5.054
365	0	.00	99.6	.4	7.30C	5.135
370	0	.00	99.6	.4	7.40C	5.217
375	0	.00	99.6	.4	7.50C	5.298
380	0	.00	99.6	.4	7.60C	5.380
385	0	.00	99.6	.4	7.70C	5.461
390	0	.00	99.6	.4	7.80C	5.543
395	1	.19	99.8	.2	7.90C	5.624
400	0	.00	99.8	.2	8.00C	5.706
405	0	.00	99.8	.2	8.10C	5.787
410	0	.00	99.8	.2	8.20C	5.869
415	0	.00	99.8	.2	8.30C	5.950
420	0	.00	99.8	.2	8.40C	6.032
425	0	.00	99.8	.2	8.50C	6.113
430	1	.19	100.0	.0	8.60C	6.195

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 13

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
1000	41.208	47.798	41208.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	2	.20	.2	99.8	.000	-.862
5	34	3.40	3.6	96.4	.121	-.758
10	51	5.10	8.7	91.3	.243	-.653
15	109	10.90	19.6	80.4	.364	-.548
20	145	14.50	34.1	65.9	.485	-.444
25	110	11.00	45.1	54.9	.607	-.339
30	92	9.20	54.3	45.7	.728	-.234
35	88	8.80	63.1	36.9	.849	-.130
40	57	5.70	68.8	31.2	.971	-.025
45	66	6.60	75.4	24.6	1.092	.079
50	37	3.70	79.1	20.9	1.213	.184
55	30	3.00	82.1	17.9	1.335	.289
60	27	2.70	84.8	15.2	1.456	.393
65	20	2.00	86.8	13.2	1.577	.498
70	21	2.10	88.9	11.1	1.699	.602
75	18	1.80	90.7	9.3	1.820	.707
80	13	1.30	92.0	8.0	1.941	.812
85	7	.70	92.7	7.3	2.063	.916
90	4	.40	93.1	6.9	2.184	1.021
95	4	.40	93.5	6.5	2.305	1.125
100	1	.10	93.6	6.4	2.427	1.230
105	2	.20	93.8	6.2	2.548	1.335
110	4	.40	94.2	5.8	2.669	1.439
115	6	.60	94.8	5.2	2.791	1.544
120	3	.30	95.1	4.9	2.912	1.648
125	3	.30	95.4	4.6	3.033	1.753
130	0	.00	95.4	4.6	3.155	1.858
135	3	.30	95.7	4.3	3.276	1.962
140	3	.30	96.0	4.0	3.397	2.067
145	3	.30	96.3	3.7	3.519	2.171
150	1	.10	96.4	3.6	3.640	2.276
155	2	.20	96.6	3.4	3.761	2.381
160	1	.10	96.7	3.3	3.883	2.485
165	2	.20	96.9	3.1	4.004	2.590
170	1	.10	97.0	3.0	4.125	2.695
175	0	.00	97.0	3.0	4.247	2.799
180	1	.10	97.1	2.9	4.368	2.904
185	1	.10	97.2	2.8	4.489	3.008
190	0	.00	97.2	2.8	4.611	3.113
195	0	.00	97.2	2.8	4.732	3.218
200	0	.00	97.2	2.8	4.853	3.322
205	1	.10	97.3	2.7	4.975	3.427
210	1	.10	97.4	2.6	5.096	3.531
215	0	.00	97.4	2.6	5.217	3.636
220	0	.00	97.4	2.6	5.339	3.741
225	0	.00	97.4	2.6	5.460	3.845
230	0	.00	97.4	2.6	5.581	3.950
235	4	.40	97.8	2.2	5.703	4.054
240	1	.10	97.9	2.1	5.824	4.159
245	2	.20	98.1	1.9	5.945	4.264
250	3	.30	98.4	1.6	6.067	4.368
255	3	.30	98.7	1.3	6.188	4.473
260	0	.00	98.7	1.3	6.309	4.577
265	0	.00	98.7	1.3	6.431	4.682
270	0	.00	98.7	1.3	6.552	4.787
275	2	.20	98.9	1.1	6.673	4.891
280	3	.30	99.2	.8	6.795	4.996
285	2	.20	99.4	.6	6.916	5.100
290	0	.00	99.4	.6	7.037	5.205
295	1	.10	99.5	.5	7.159	5.310
300	2	.20	99.7	.3	7.280	5.414
305	0	.00	99.7	.3	7.401	5.519
310	0	.00	99.7	.3	7.523	5.624
315	0	.00	99.7	.3	7.644	5.728
320	0	.00	99.7	.3	7.765	5.833
325	0	.00	99.7	.3	7.887	5.937
330	0	.00	99.7	.3	8.008	6.042
335	1	.10	99.8	.2	8.129	6.147
340	0	.00	99.8	.2	8.251	6.251
345	0	.00	99.8	.2	8.372	6.356
350	0	.00	99.8	.2	8.493	6.460
355	0	.00	99.8	.2	8.615	6.565
360	0	.00	99.8	.2	8.736	6.670
365	0	.00	99.8	.2	8.858	6.774
370	0	.00	99.8	.2	8.979	6.879
375	0	.00	99.8	.2	9.100	6.983
380	0	.00	99.8	.2	9.222	7.088
385	0	.00	99.8	.2	9.343	7.193
390	0	.00	99.8	.2	9.464	7.297
395	1	.10	99.9	.1	9.586	7.402
400	0	.00	99.9	.1	9.707	7.506
405	0	.00	99.9	.1	9.828	7.611
410	0	.00	99.9	.1	9.950	7.716
415	0	.00	99.9	.1	10.071	7.820
420	0	.00	99.9	.1	10.192	7.925
425	0	.00	99.9	.1	10.314	8.030
430	1	.10	100.0	.0	10.435	8.134

REMAINING FREQUENCIES ARE ALL ZERO

APPENDIX B

DESIGN AND RESULTS

OF EXPERIMENT 3

		CM_ℓ 0.4 Uncl	0.4 Clas	0.3 Uncl	0.3 Clas	0.2 Uncl	0.2 Clas
		C_k					
FLASH	0.01 - 0.24	23.0	42.5	23.8	76.0	23.8	41.5
		21.6	39.8	22.8	38.0	21.4	38.7
		25.3	44.7	23.5	69.0	23.5	49.3
		22.1	58.3	23.9	45.8	26.0	46.3
	0.25 - 0.49	25.2	52.1	27.0	51.2	28.3	60.1
		26.5	54.5	25.1	43.2	25.6	43.1
		26.7	58.6	27.4	37.9	24.9	40.0
		24.8	54.6	26.1	46.9	24.2	41.9
	0.50 - 0.74	25.8	53.9	23.3	43.3	25.7	42.1
		28.6	62.5	28.8	50.0	26.8	36.5
		24.7	39.8	24.9	38.4	25.3	44.5
		29.1	39.8	29.4	43.4	27.1	46.5
	0.75 - 1.00	29.5	57.9	29.0	37.2	31.0	38.3
		29.2	43.3	26.8	53.4	29.7	40.5
		30.1	43.1	29.0	49.6	31.7	43.3
		31.2	47.1	29.7	42.3	31.4	41.3
IMMEDIATE	0.01 - 0.24	22.6	51.5	24.8	55.4	22.7	60.4
		20.4	55.9	24.9	49.3	23.3	46.8
		23.7	54.3	23.2	47.1	24.8	36.2
		21.8	55.6	26.8	55.6	27.3	42.6
	0.25 - 0.49	29.8	74.3	30.4	63.7	32.4	54.2
		22.9	60.0	24.6	64.9	25.2	53.2
		24.2	69.4	24.6	58.1	26.1	52.1
		28.3	85.4	28.3	67.5	28.8	57.2
	0.50 - 0.74	25.7	125.4	28.0	135.5	29.3	66.2
		30.3	157.0	30.5	88.5	35.0	68.6
		27.8	137.1	27.6	94.9	28.1	46.5
		28.8	546.5	30.7	116.8	30.8	78.1
	0.75 - 1.00	31.6	326.0	34.6	253.0	34.9	88.0
		28.3	1044.0	27.3	129.6	29.1	83.8
		26.7	1053.9	28.1	171.3	32.2	71.0
		27.1	353.8	28.1	165.4	28.7	59.4

		CM_ℓ					
		0.4		0.3		0.2	
		C_k					
		Uncl	Clas	Uncl	Clas	Uncl	Clas
PRIORITY	0.01 - 0.24	26.2 24.0 21.8 27.8	189.4 72.8 78.0 112.8	29.4 23.6 24.9 25.8	117.6 88.0 54.6 66.0	33.6 27.0 16.2 24.9	55.3 48.6 20.1 56.1
	0.25 - 0.49	22.1 26.0 26.9 25.0	64.6 81.0 72.1 105.3	25.6 27.0 27.0 26.1	64.5 69.2 63.6 70.3	24.0 27.0 26.2 26.8	59.7 56.2 66.2 57.0
	0.50 - 0.74	25.9 26.6 28.3 27.0	787.6 1225.8 525.6 374.3	27.7 25.5 29.3 29.0	408.8 442.5 121.5 98.4	31.9 31.3 30.2 26.6	106.5 79.5 63.9 50.6
	0.75 - 1.00	26.4 26.8 25.8 28.9	1201.0 1124.0 1395.9 1568.8	29.6 28.2 27.0 26.1	285.0 143.3 284.5 384.3	28.9 26.0 30.8 27.9	54.1 50.0 78.7 74.8
ROUTINE	0.01 - 0.24	38.3 31.9 30.3 28.8	758.6 701.1 1342.9 240.7	44.8 40.8 36.0 39.9	174.4 223.1 711.0 55.7	35.2 41.7 32.1 36.2	53.7 61.5 53.5 56.3
	0.25 - 0.49	32.6 29.2 28.3 24.9	936.6 261.4 2003.6 1684.1	31.9 30.9 32.0 31.1	553.8 82.9 416.9 524.7	34.7 34.7 30.6 28.3	151.1 66.3 241.9 60.1
	0.50 - 0.74	27.9 27.7 27.9 27.7	3130.7 761.2 1364.8 651.4	30.9 33.5 29.8 27.4	247.5 723.1 890.5 265.2	34.2 30.4 31.9 28.4	114.4 66.4 86.3 69.2
	0.75 - 1.00	27.5 28.7 23.8 26.3	1211.2 783.2 1751.2 1665.0	31.8 31.6 25.4 29.8	236.2 345.9 369.5 439.6	31.5 31.7 28.8 28.0	198.8 65.6 87.2 70.6

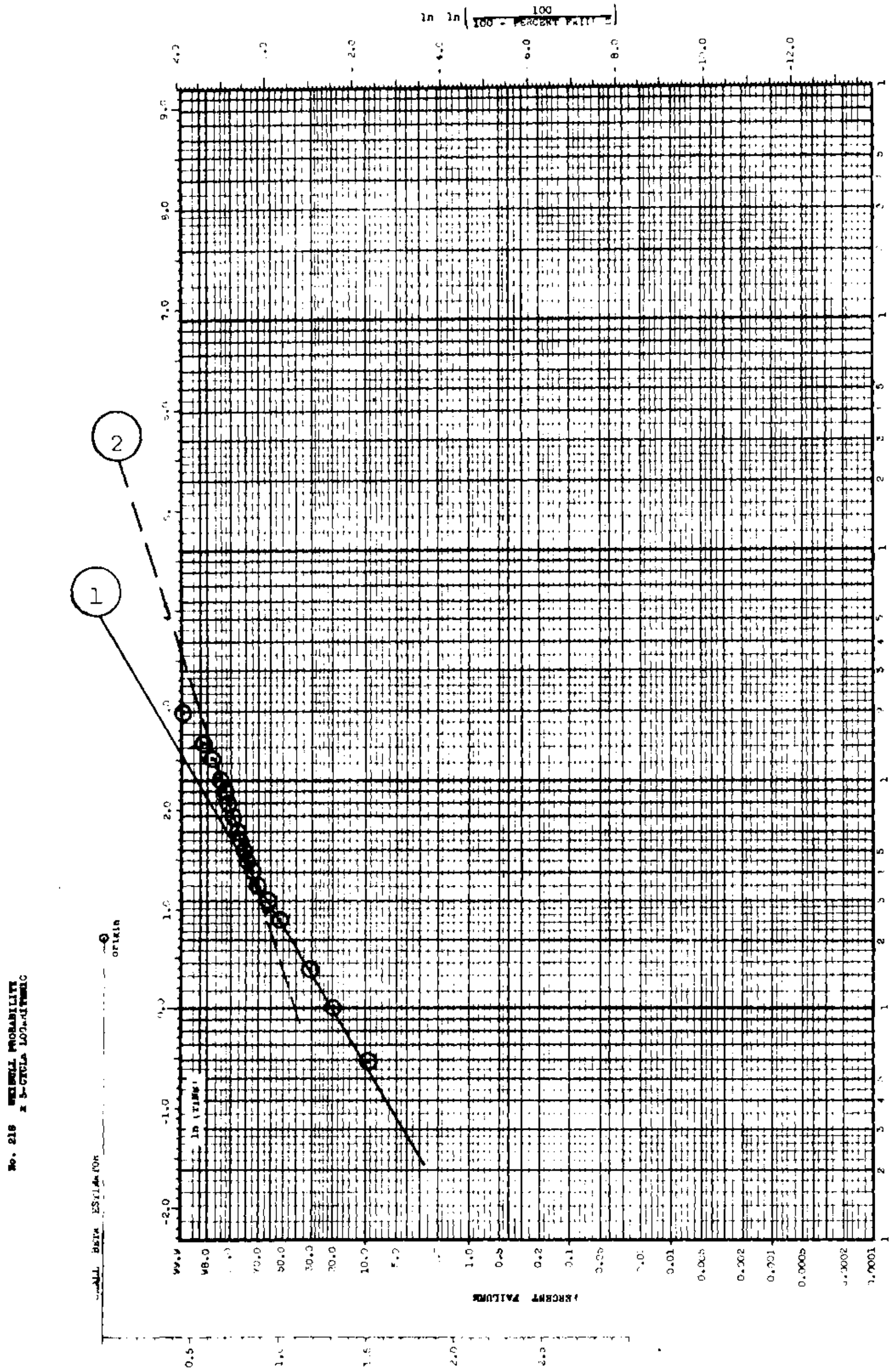
ANOVA

Source	d.f	Sum of Squares	Mean Square	EMS	F
PM_i	3	886,597.78	295,532.59	9.38	2.65*
P_j	3	3,686,989.95	1,228,996.65	39.01	2.65*
C_k	1	4,911,005.63	4,911,005.63	155.90	3.89*
CM_l	2	3,561,585.87	1,780,792.94	56.53	3.04*
PMP_{ij}	9	718,799.56	79,866.62	2.54	1.93*
PMC_{ik}	3	859,858.29	286,619.43	9.10	2.65*
$PMCM_{il}$	6	1,009,014.87	168,169.15	5.34	2.14*
PC_{jk}	3	3,551,499.47	1,183,833.16	37.58	2.65*
PCM_{jl}	6	2,955,066.40	492,511.07	15.63	2.14*
CCM_{kl}	2	3,623,343.98	1,811,671.99	57.51	3.04*
$PMPC_{ijk}$	9	738,704.05	82,078.23	2.61	1.93*
$PMPCM_{ijl}$	18	757,132.53	42,062.92	1.34	1.62
$PMCCM_{ikl}$	6	1,006,588.41	167,764.74	5.33	2.14*
$PCCM_{jkl}$	6	2,989,890.18	498,315.03	15.82	2.14*
$PMPCCM_{ijkl}$	18	757,859.59	42,103.31	1.34	1.62
εmci_jkl	228	9,072,565.69	31,501.96		
Total	383	41,086,502.25			

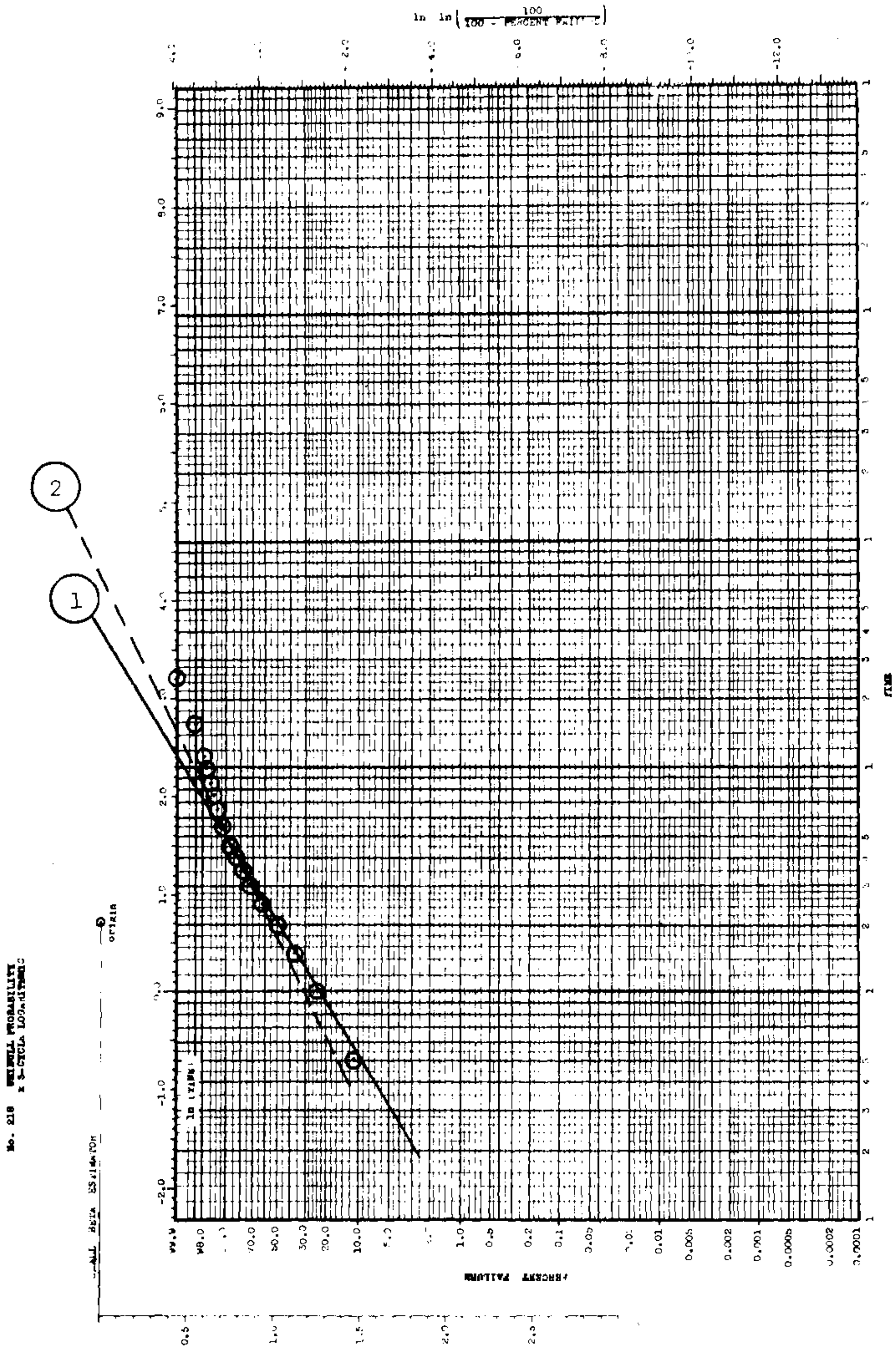
*Effect is significant at a 5 per cent level of significance.

APPENDIX C

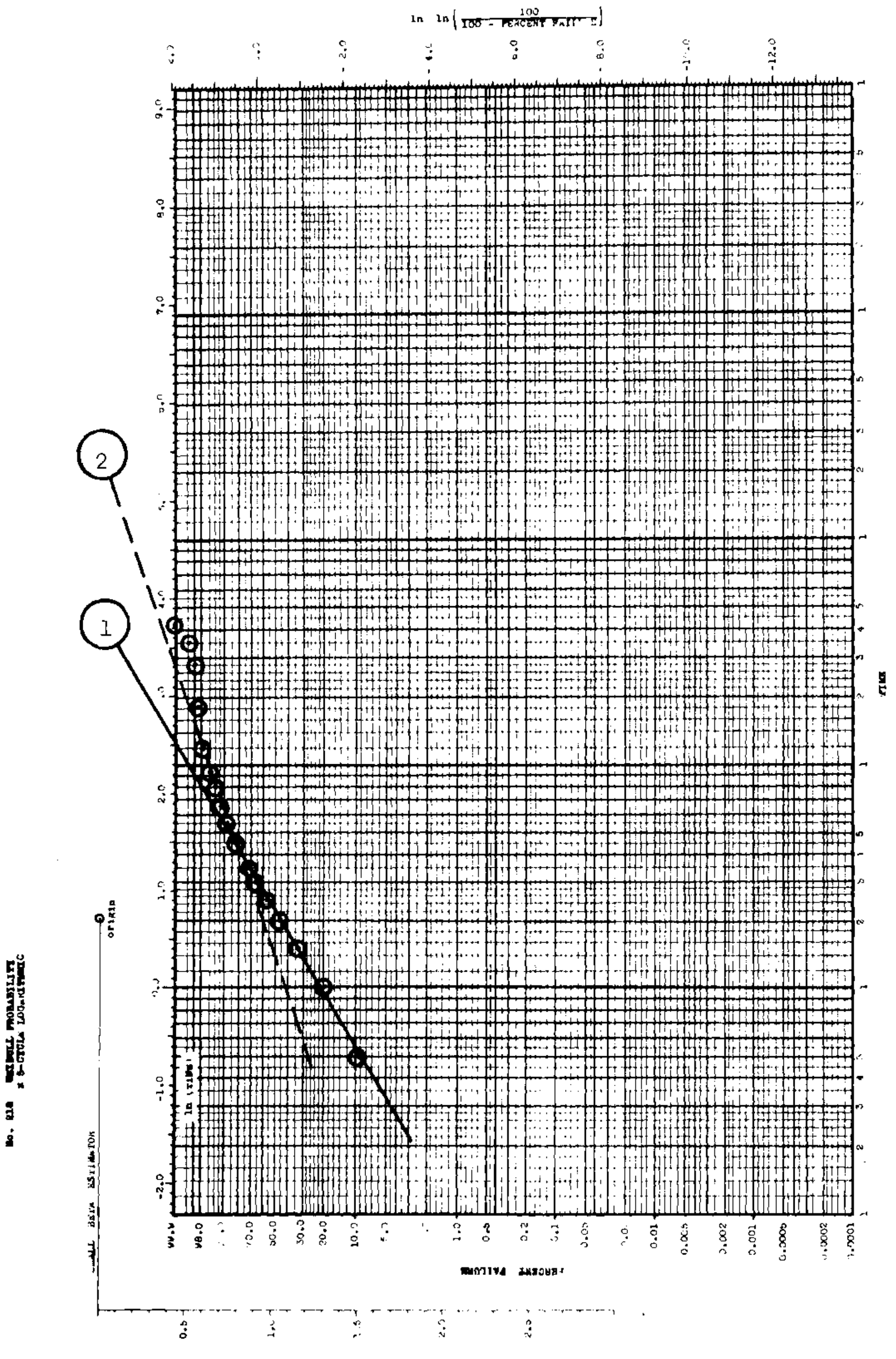
WEIBULL PLOTS FROM WHICH α AND β WERE ESTIMATED IN EXPERIMENT 4



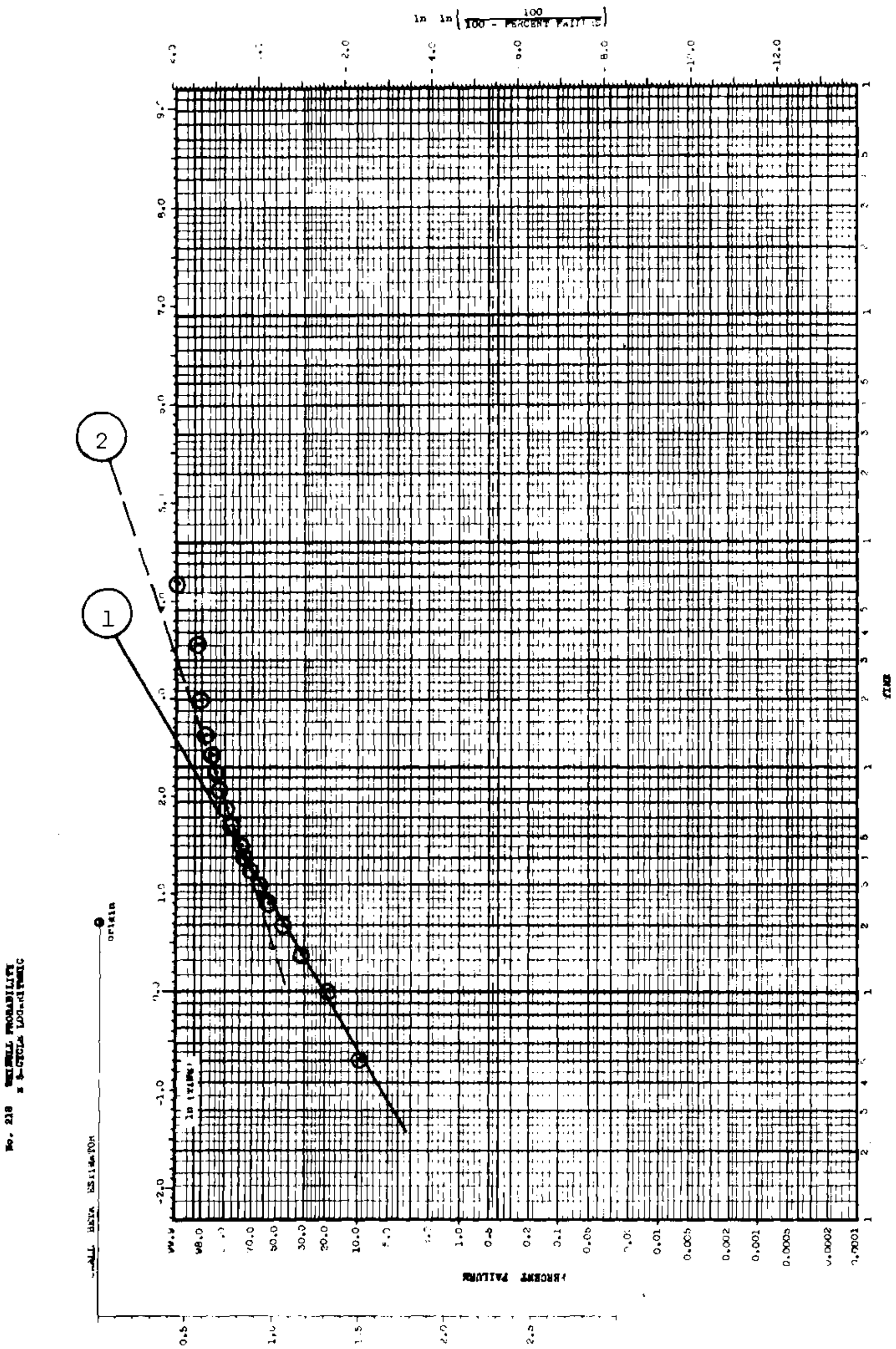
Plot 1. (See Table 32)



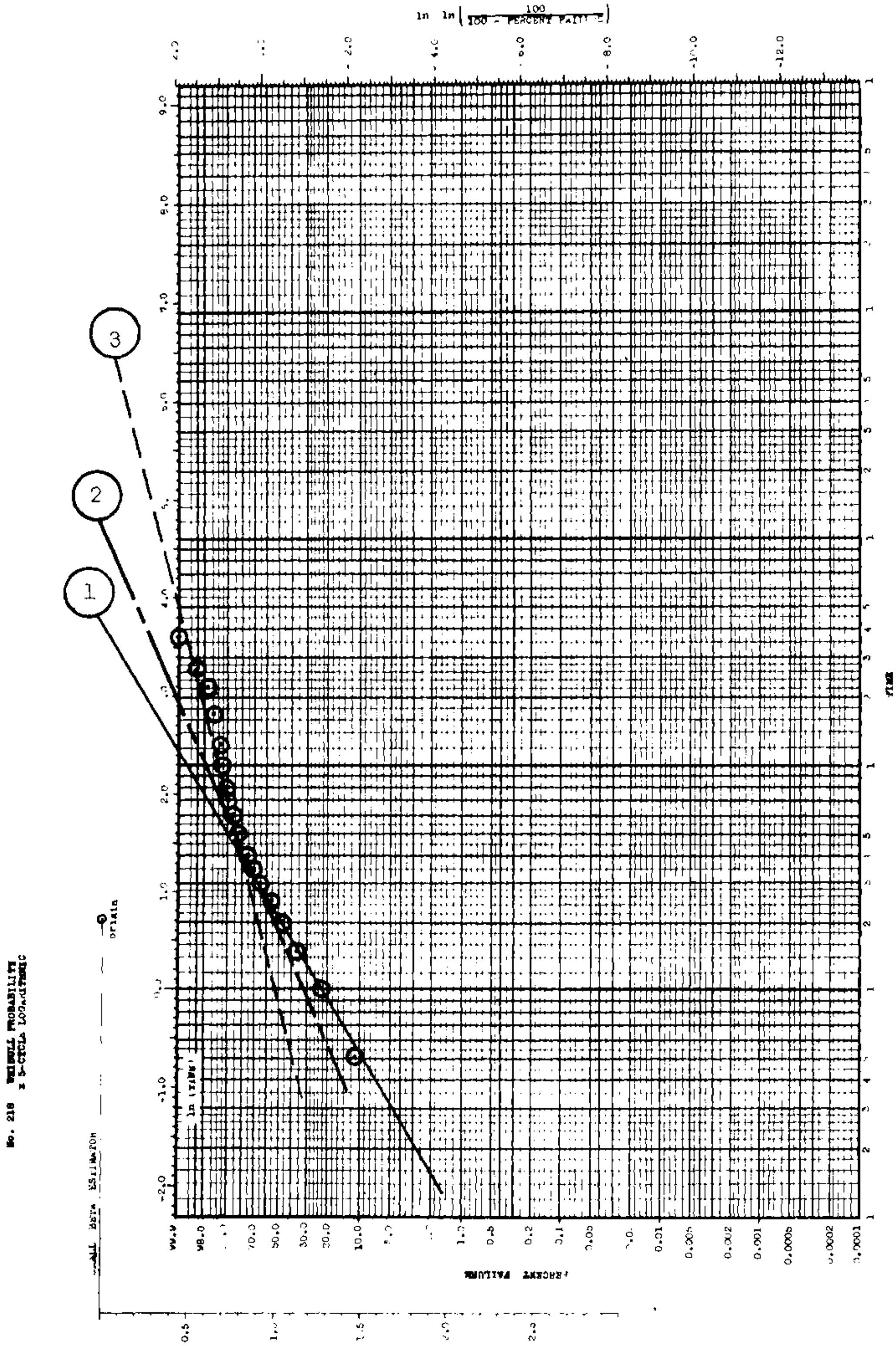
Plot 2. (See Table 32)



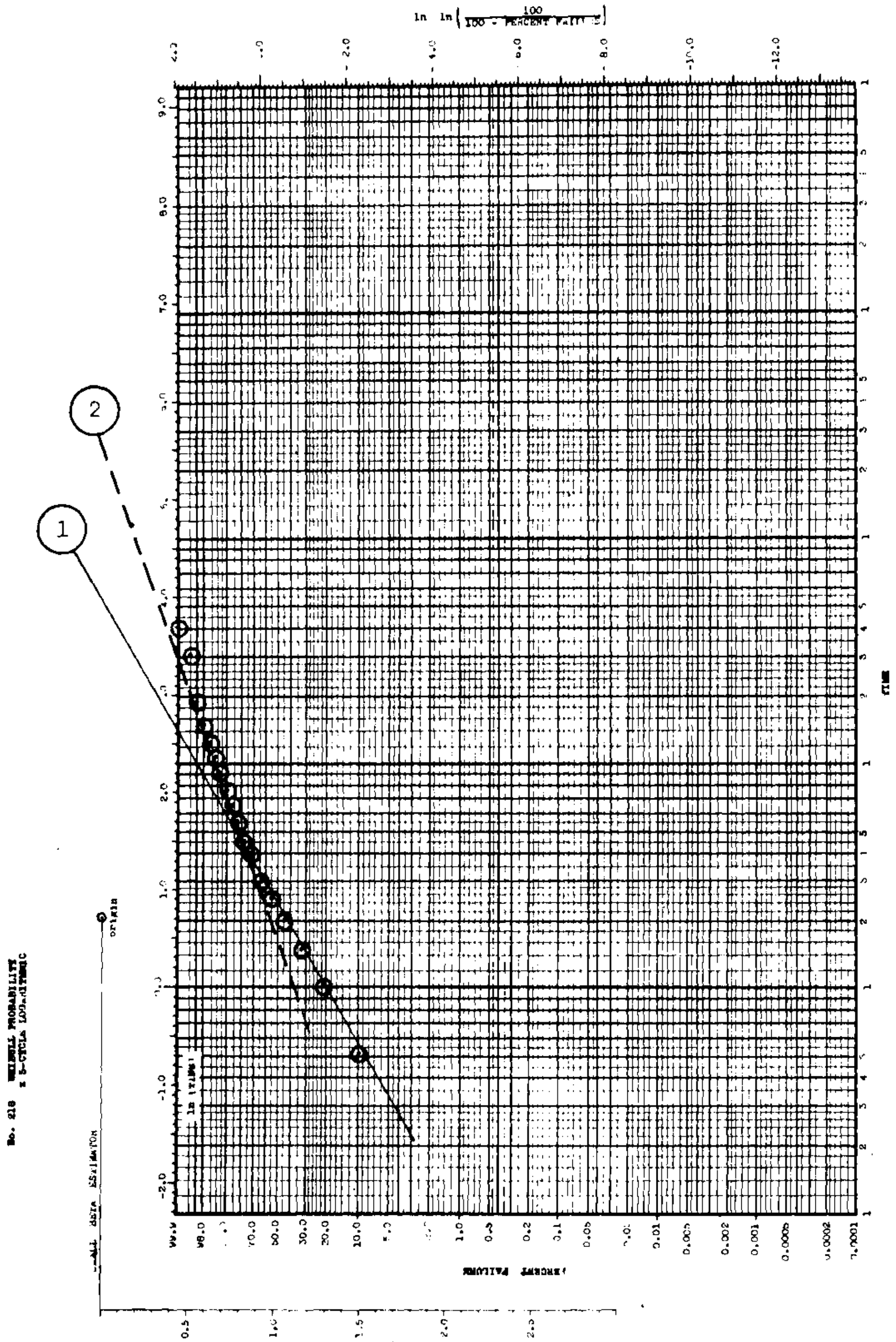
Plot 3. (See Table 32)



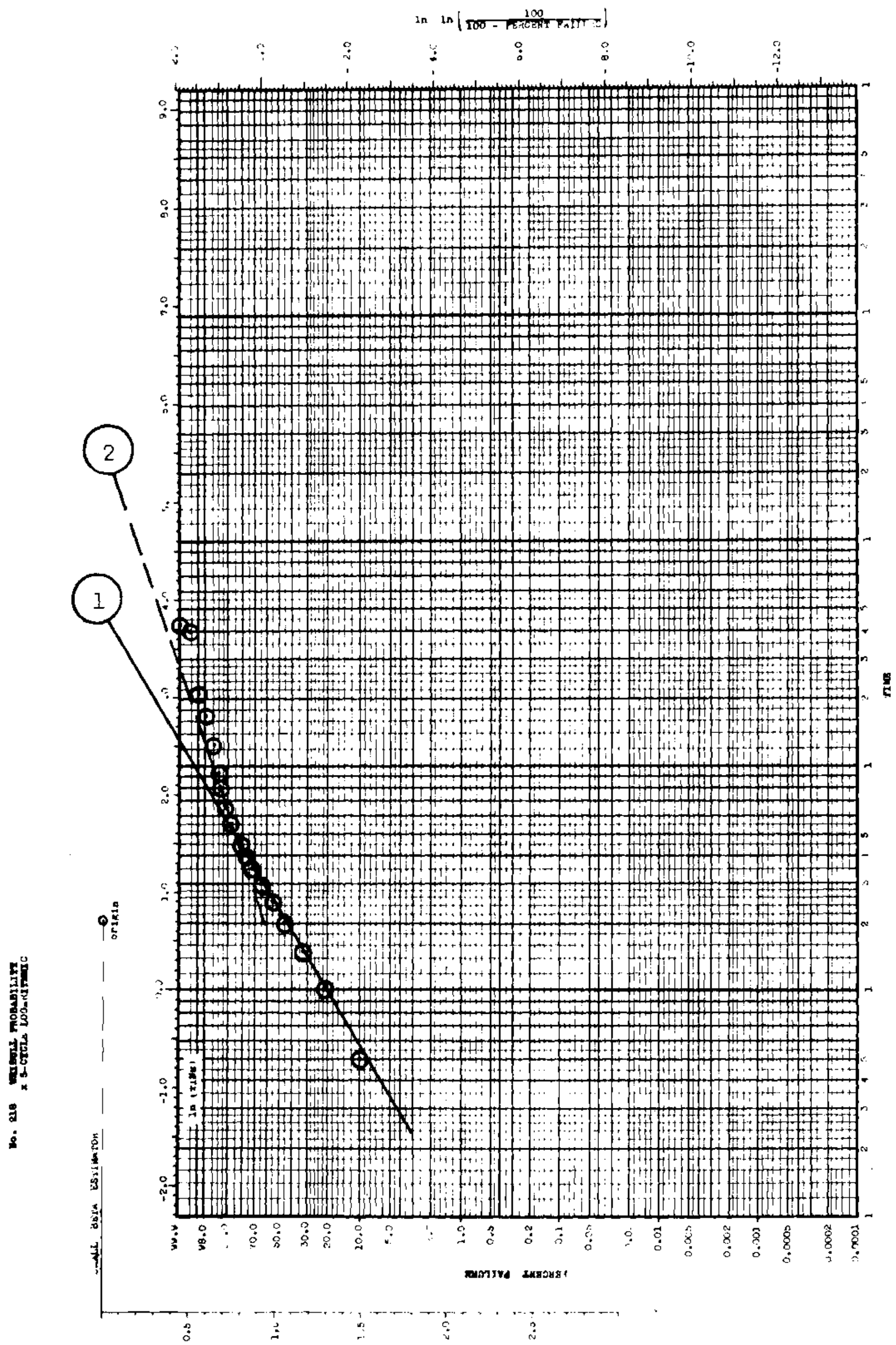
Plot 4. (See Table 32)



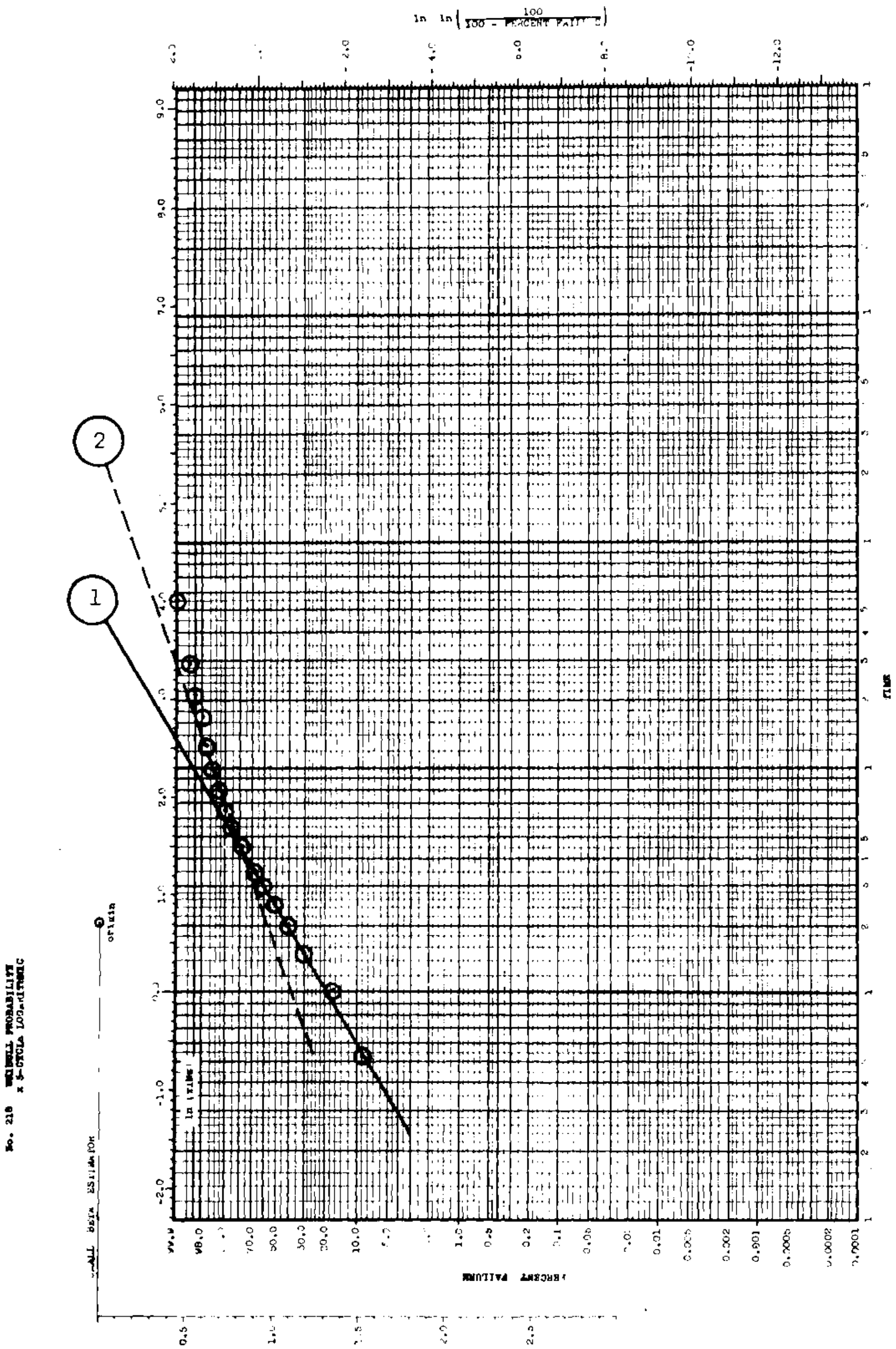
Plot 5. (See Table 32)



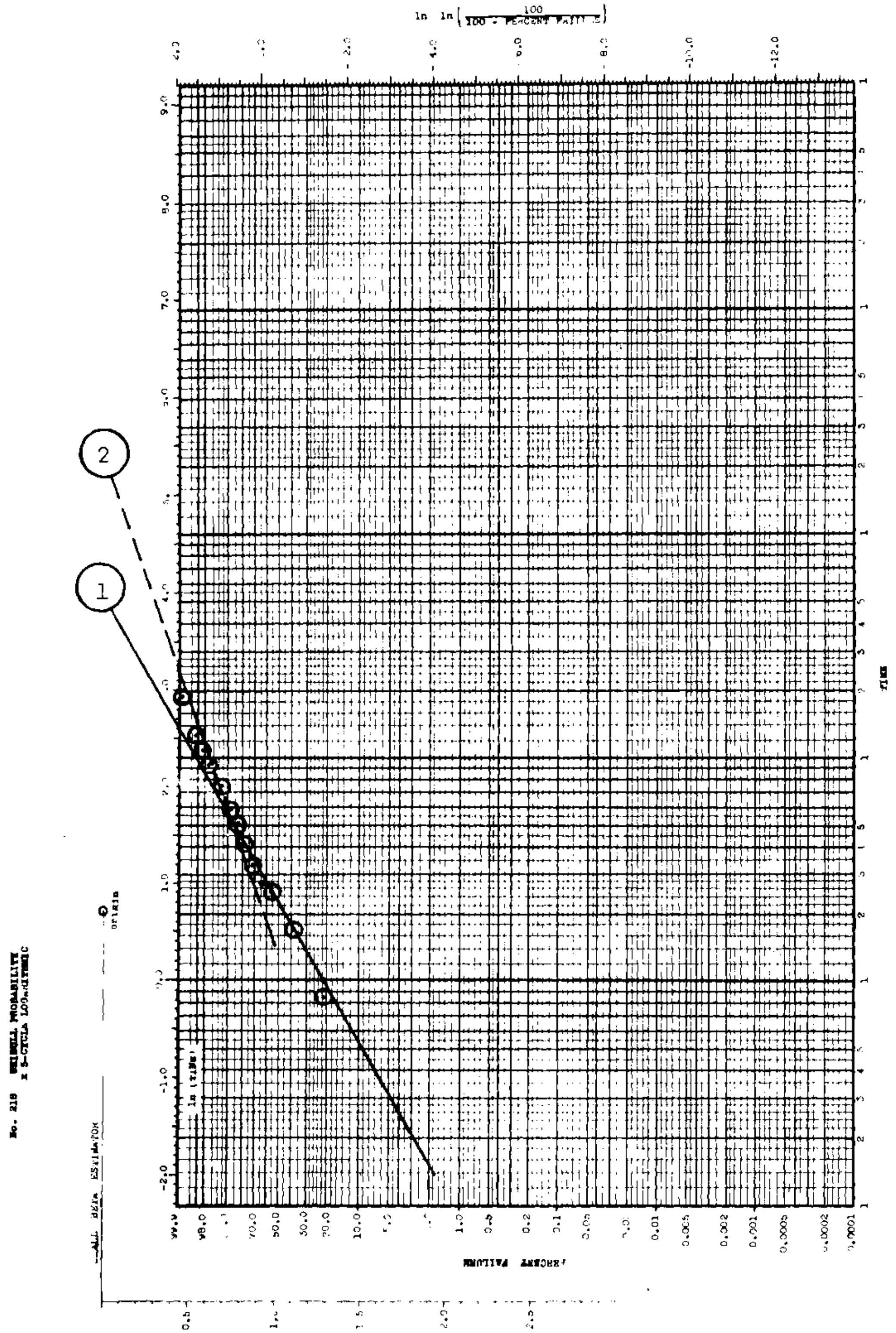
Plot 6. (See Table 32)



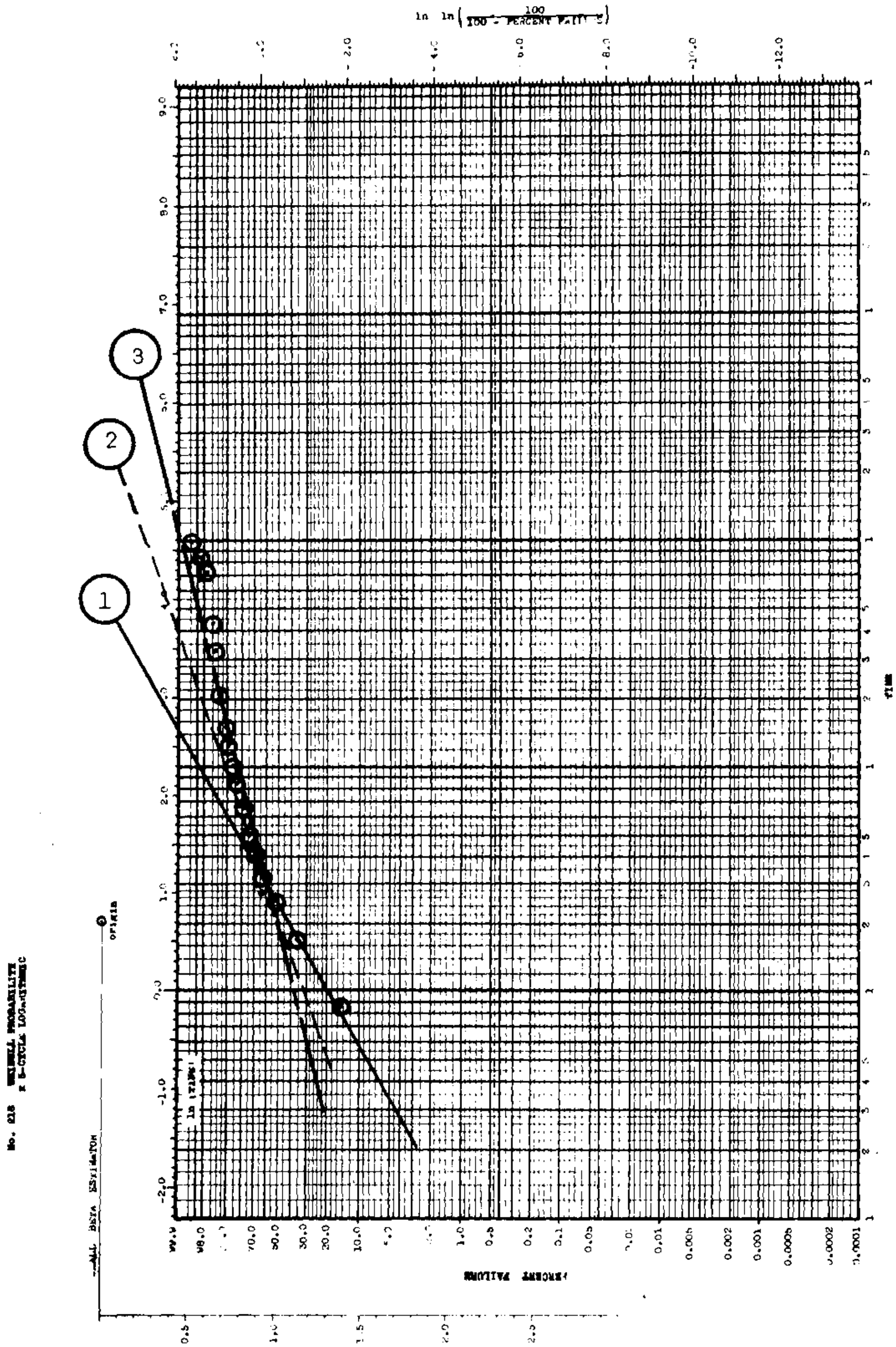
Plot 7. (See Table 32)



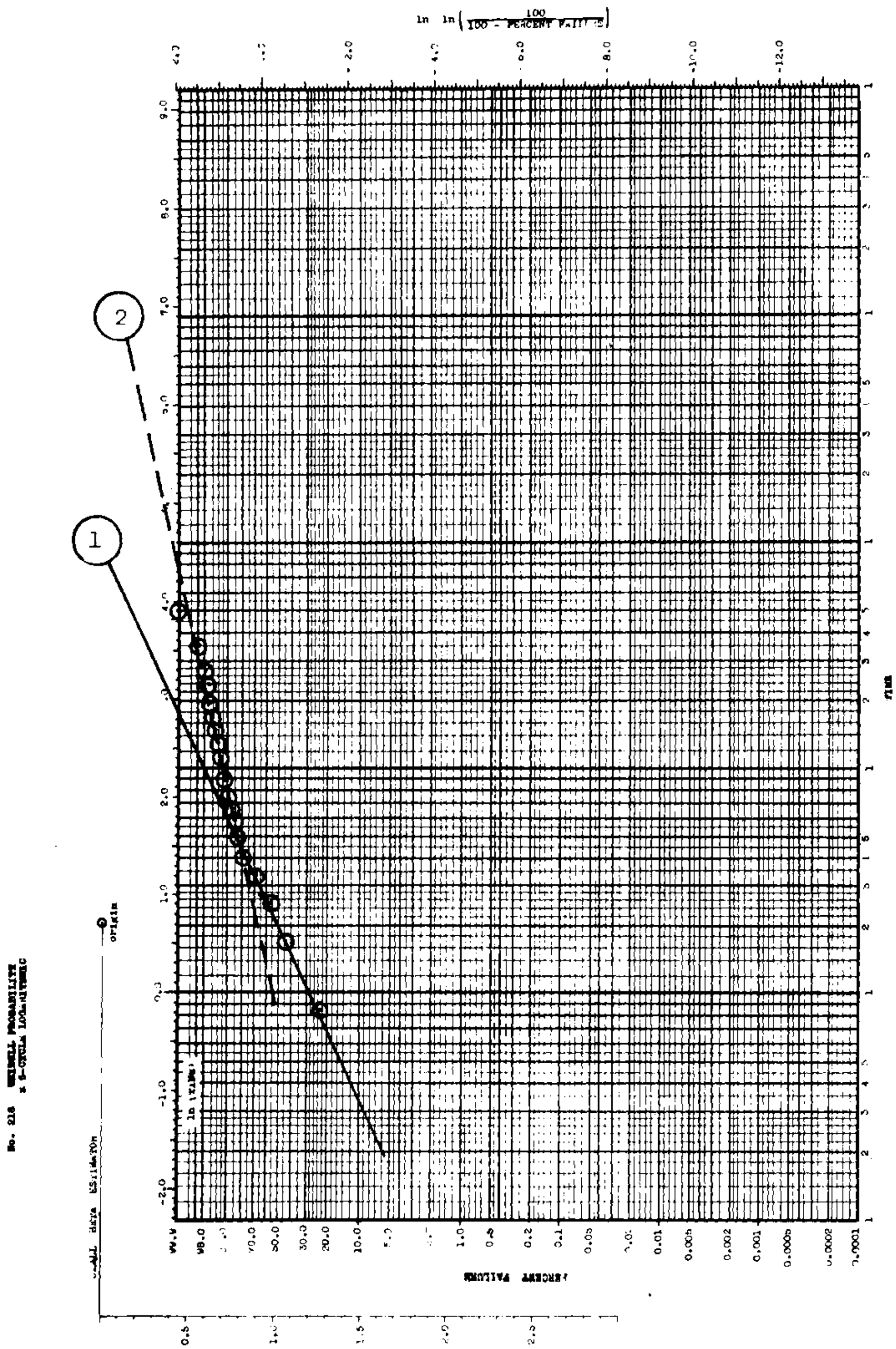
Plot 8. (See Table 32)



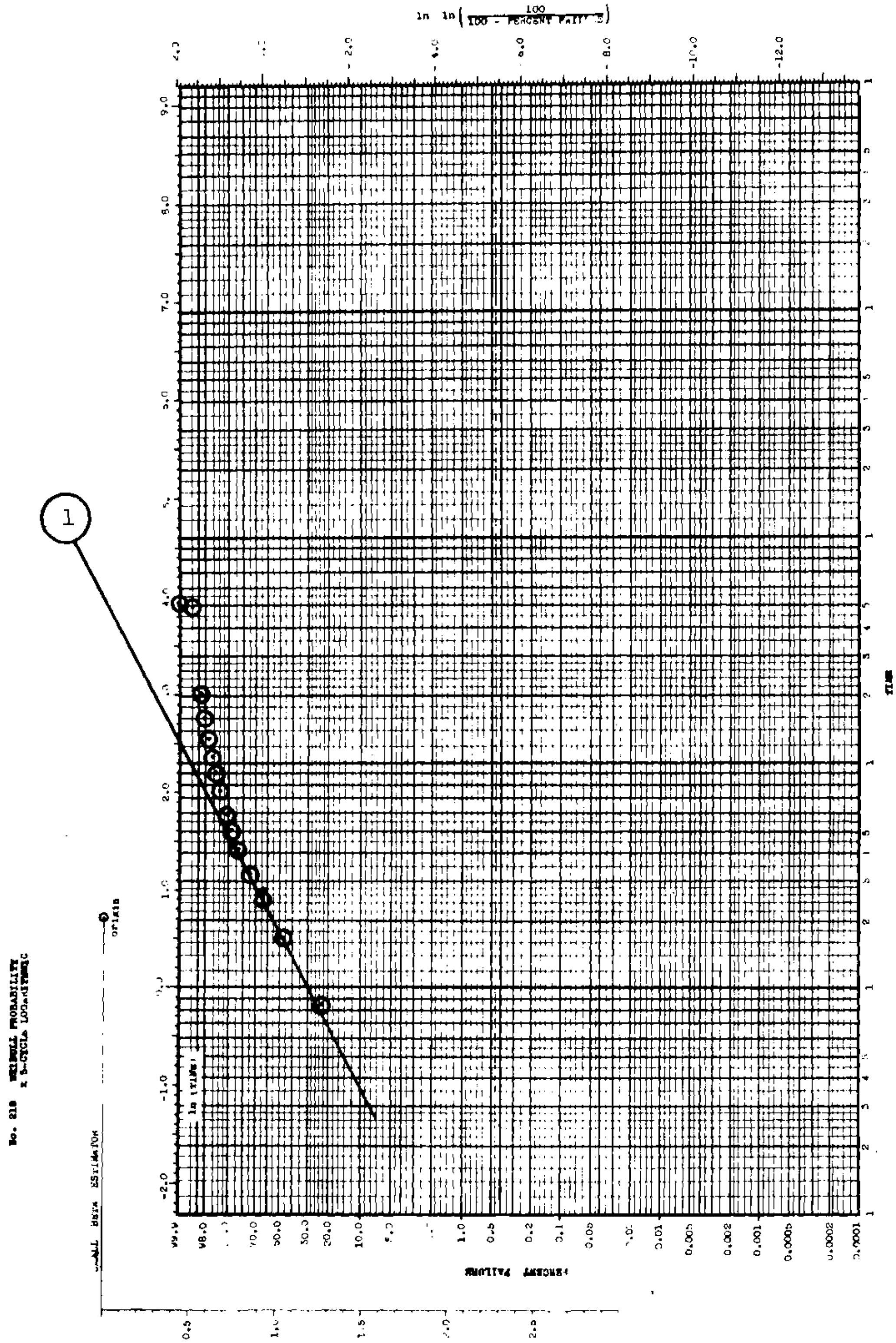
Plot 9. (See Table 32)



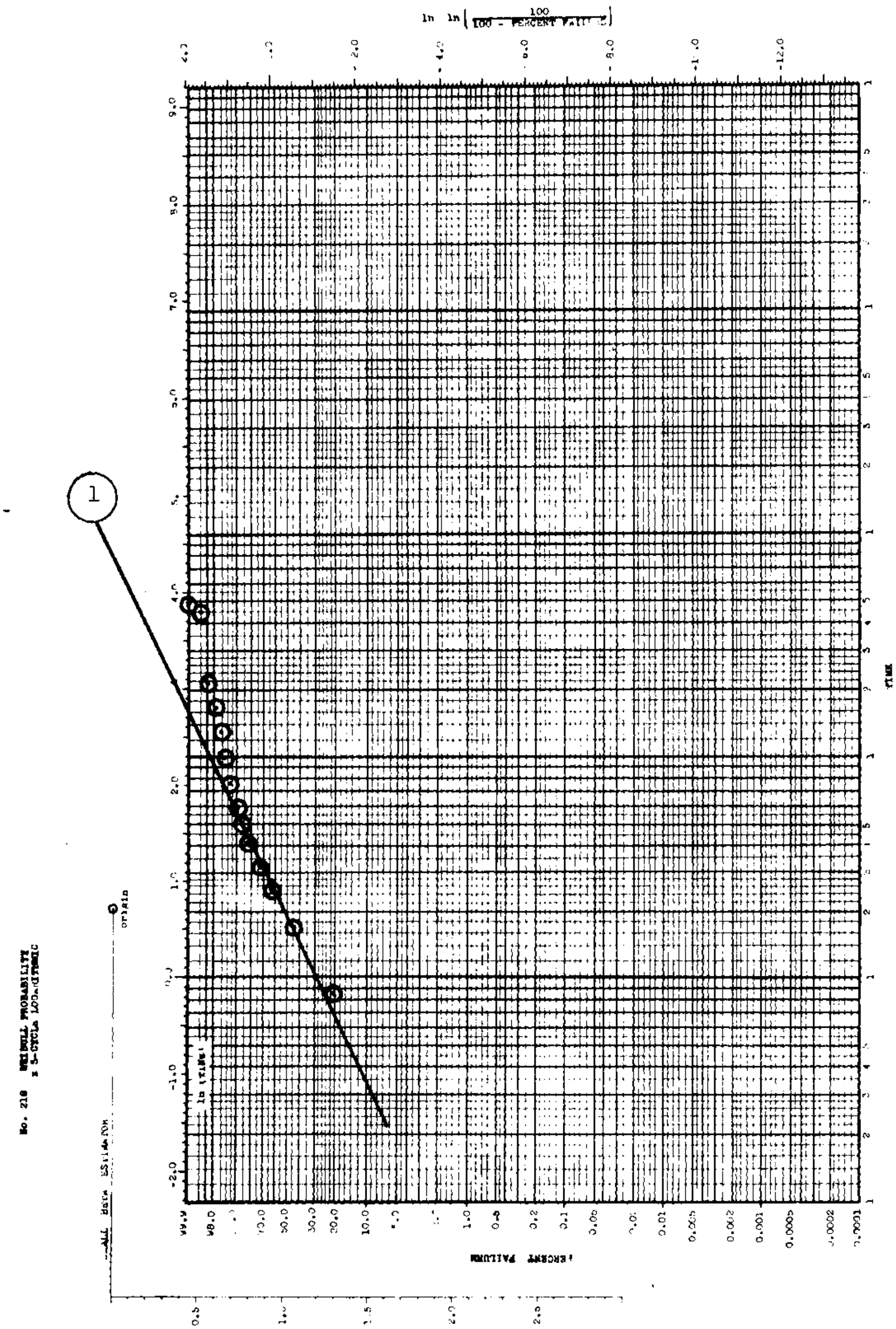
Plot 10. (See Table 32)



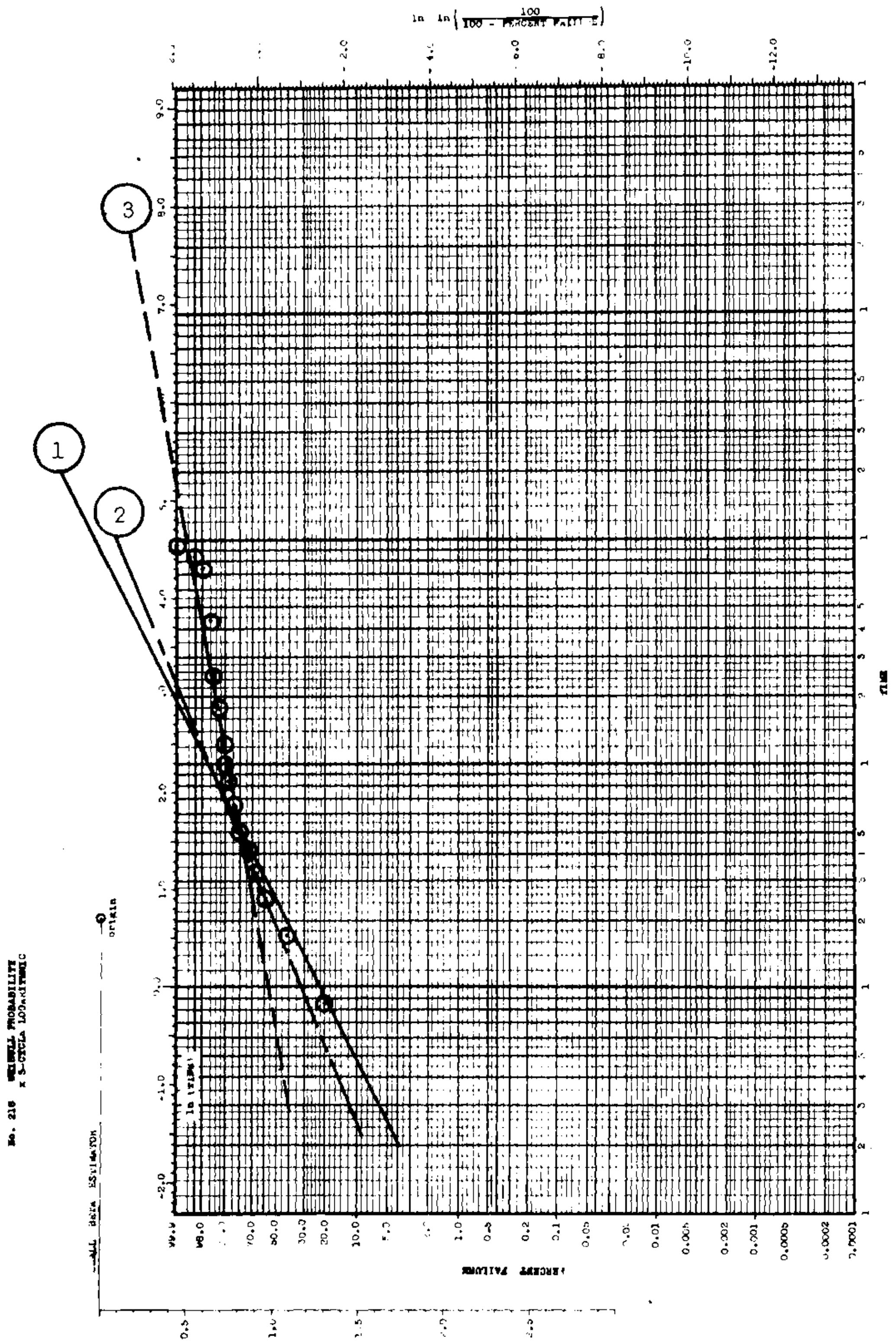
Plot 11. (See Table 32)



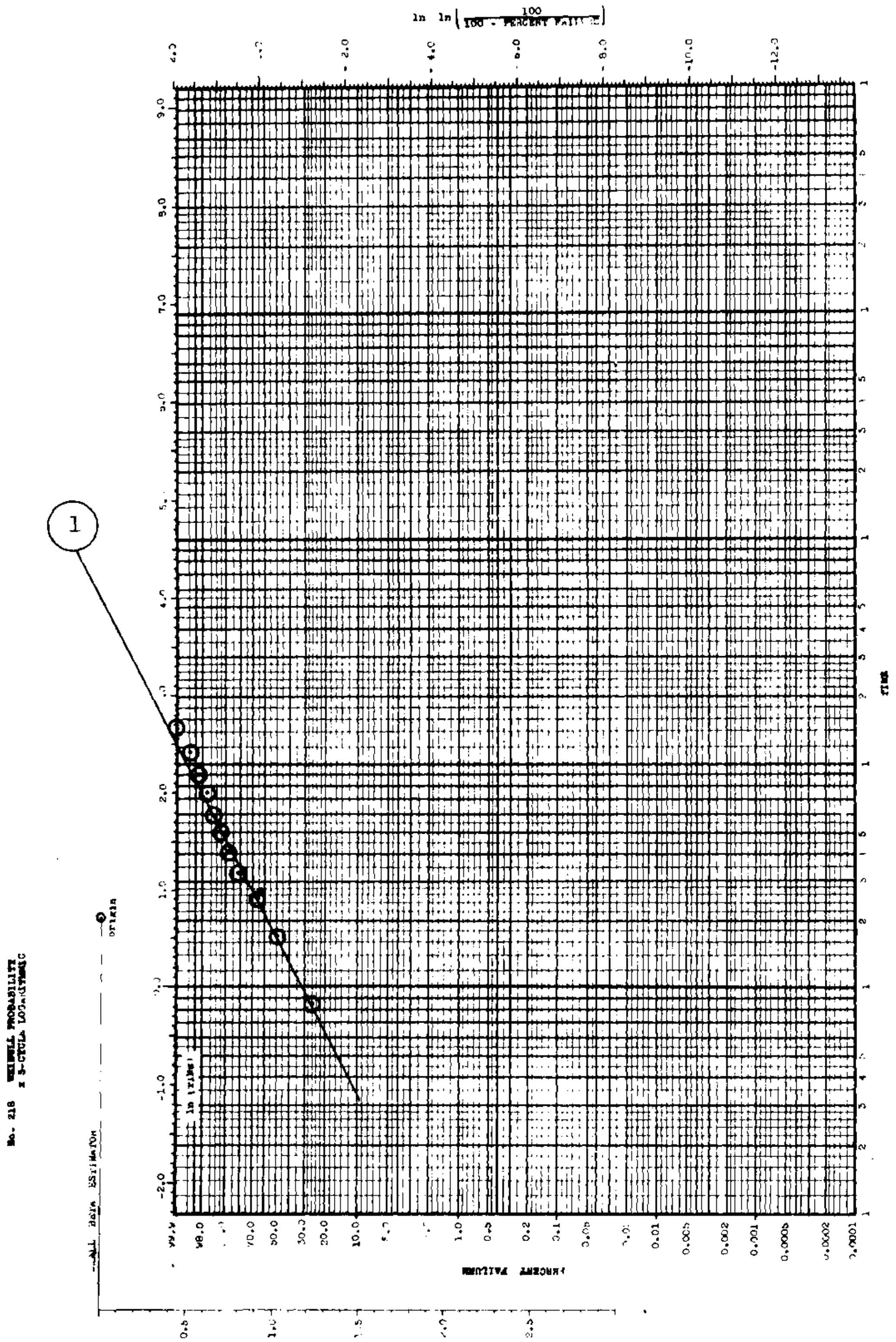
Plot 12. (See Table 32)



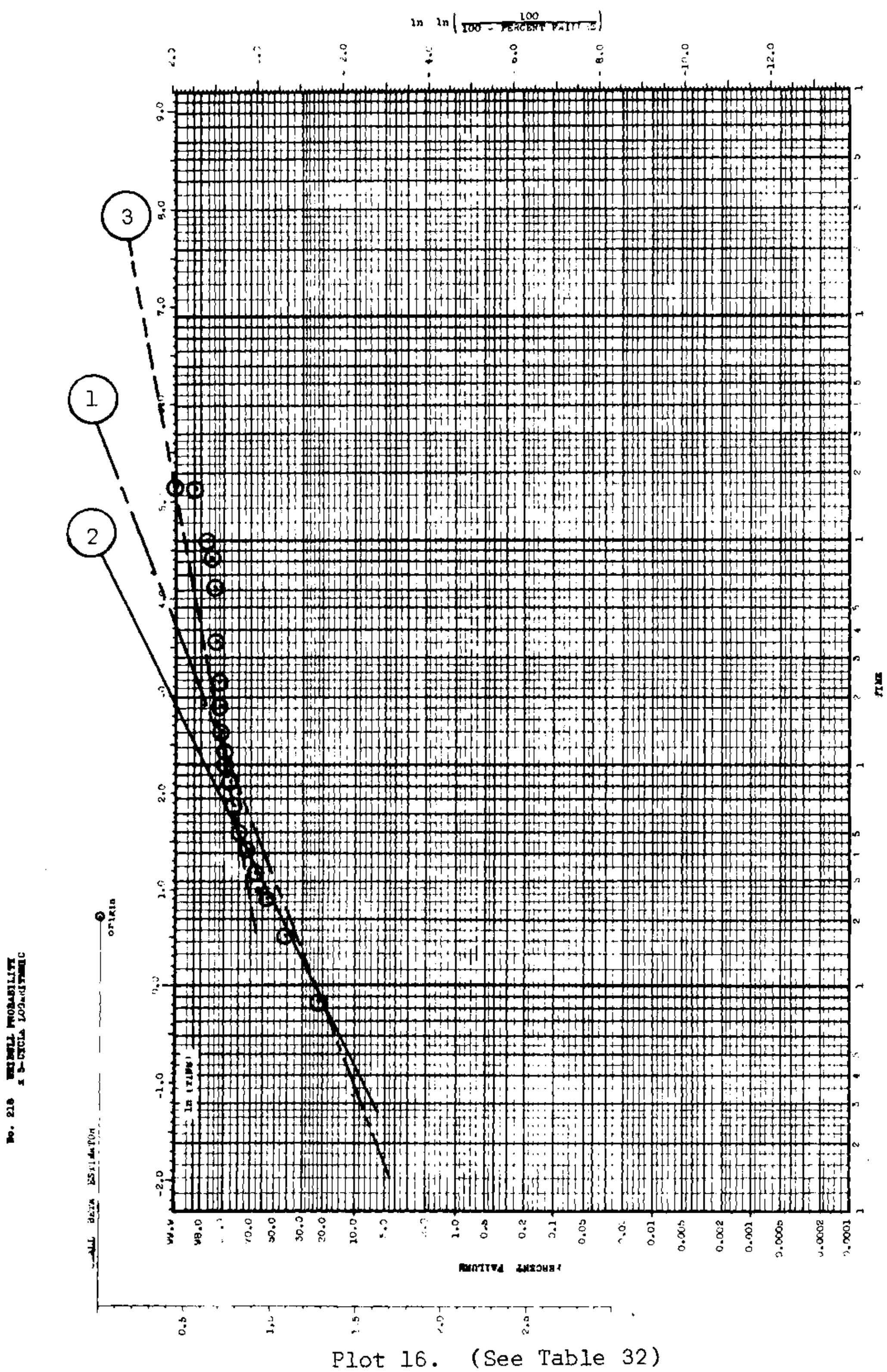
Plot 13. (See Table 32)



Plot 14. (See Table 32)



Plot 15. (See Table 32)



Plot 16. (See Table 32)

APPENDIX D

ALGOL COMPUTER PROGRAM FOR GOODNESS OF FIT TEST IN EXPERIMENT 4

```
2         COMMENT ROBERT L LONGSHORE IE 700 GOODNESS OF FIT TEST            $
2         REAL (T,Y,FO,F,Z,A,B,D,DIF)                                       $
2         INTEGER (I,S,K,N,X,L,SUMN,J,M)                                    $
2         ARRAY (X(150),N(150),T(150),Y(150),Z(150),F(150),DIF(150),
2               A(8),B(8))                                                  $
2         INPUT IN1(L,M,(FOR J=(1,1,M)$(A(J),B(J))),
2               (FOR I=(1,1,L)$(X(I),N(I))))                                $
2         OUTPUT OUT1(X(I),N(I),T(I),FO,F(I),DIF(I))                        $
2         OUTPUT OUT2(SUMN)                                                 $
2         OUTPUT OUT3(J,A(J),J,B(J))                                        $
2         FORMAT FMT1(B5,*OBSERVED TIME   NUMBER OBSERVED*,B3,
2                *ADJUSTED TIME   F(T) OBSERVED   F(T) CALCULATED*,B3,
2                *ABS DIFFERENCE*,W6)                                       $
2         FORMAT FMT2(B7,I6,B13,I4,B8,X11.4,B9,X5.3,B13,X6.4,B11,X6.4,
2                W0)                                                        $
2         FORMAT FMT3(B32,*ALPHA*,I2,* =*,X8.4,B5,*BETA*,I2,* =*,X8.4,
2                W6)                                                        $
2         FORMAT FMT4(B5,*EXCEEDS CONFIDENCE LIMITS, REJECT HYPOTHESIS*,
2                W0)                                                        $
2         FORMAT FMT5(B5,*TOTAL OBSERVATIONS =*,I4,W6)                      $
2         FORMAT FMT6(W1)                                                   $
2         READ ($$IN1)                                                      $
2         WRITE ($$FMT1)                                                    $
2         FO=0.0                                                            $
2         SUMN=0                                                            $
2         J=1                                                               $
2         S=1                                                               $
2         FOR I=(1,1,L)                                                     $
2    BEGIN
2         SUMN=((SUMN)+(N(I)))                                              $
2    END                                                                    $
2         D=((1.36)/(SQRT (FLOAT(SUMN))))                                   $
2         WRITE ($$OUT3,FMT3)                                               $
2         FOR I=(1,1,L)                                                     $
2    BEGIN
2         K=(I)-(1)                                                         $
2         IF K EQL 0                                                        $
2    BEGIN
2         X(K)=0                                                            $
2    END                                                                    $
2         Y(I)=(((((FLOAT(N(I))).(FLOAT(X(I))))+(FLOAT(X(K))))/
2              ((FLOAT(N(I)))+(1.0)))/(60.0))                               $
2         T(I)=((Y(I))-(Y(S)))                                              $
2         FO=FO+((FLOAT(N(I)))/(FLOAT(SUMN)))                               $
2L1..     Z(I)=((((T(I))/(10.0))*(B(J)))/(A(J)))                            $
2         F(I)=((1.0)-(EXP (-(Z(I)))))                                      $
2         DIF(I)=(ABS ((F(I))-(FO)))                                        $
2         IF DIF(I) GTR D                                                   $
2    BEGIN
2         J=((J)+(1))                                                       $
2         IF J GTR M                                                        $
2    BEGIN
2         WRITE ($$FMT4)                                                    $
2         WRITE ($$FMT6)                                                    $
2         READ ($$IN1)                                                      $
2    END                                                                    $
2         WRITE ($$OUT3,FMT3)                                               $
2         GO TO L1                                                          $
2    END                                                                    $
2         WRITE ($$OUT1,FMT2)                                               $
2    END                                                                    $
2         WRITE ($$OUT2,FMT5)                                               $
2         WRITE ($$FMT6)                                                    $
2         READ ($$IN1)                                                      $
2FINISH                                                                     $
```

APPENDIX E

TABLES

Table 8. Precedence Mix for Experiment 1

Model	Flash	Immediate	Priority	Routine
1	0	0	0.50	0.50
2	0	0	0.25	0.75
3	0	0	0.75	0.25
4	0	0.25	0.25	0.50
5	0	0.50	0.25	0.25
6	0	0.25	0.50	0.25
7	0.25	0.25	0.25	0.25
8	0.25	0	0.25	0.50
9	0.25	0	0.50	0.25
10	0.25	0	0.75	0
11	0.50	0.25	0.25	0
12	0.50	0.50	0	0
13	0.75	0.25	0	0
14	1.00	0	0	0
15	0	0	0	1.00

Table 9. Precedence Mix for Experiment 2

Model	Flash	Immediate	Priority	Routine
1	0	0.05	0.40	0.55
2	0	0.10	0.40	0.50
3	0	0.10	0.35	0.55
4	0	0.15	0.40	0.45
5	0	0.15	0.35	0.50
6	0	0.15	0.30	0.55
7	0	0	0.25	0.75
8	0	0	0.35	0.65
9	0	0	0.45	0.55
10	0	0.10	0.25	0.65
11	0	0.10	0.45	0.45
12	0	0.20	0.25	0.55
13	0	0.20	0.35	0.45
14	0	0.20	0.45	0.35
15	0	0	0.15	0.85
16	0	0	0.55	0.45
17	0	0.10	0.15	0.75
18	0	0.10	0.55	0.35
19	0	0.20	0.15	0.65

Table 9. Precedence Mix for Experiment 2 (Continued)

Model	Flash	Immediate	Priority	Routine
20	0	0.20	0.55	0.25
21	0	0.30	0.15	0.55
22	0	0.30	0.15	0.45
23	0	0	0.65	0.35
24	0	0.10	0.65	0.25
25	0	0.20	0.65	0.15
26	0	0.30	0.65	0.05
27	0	0	0.75	0.25
28	0	0.10	0.75	0.15
29	0	0.20	0.75	0.05
30	0	0	0.85	0.15
31	0	0.10	0.85	0.05
32	0	0	0.95	0.05
33	0.05	0.05	0.40	0.50
34	0.05	0.05	0.40	0.50
35	0.05	0.05	0.35	0.55
36	0.05	0.10	0.35	0.50
37	0.05	0.10	0.40	0.45
38	0.05	0.15	0.30	0.50
39	0.05	0.15	0.35	0.45
40	0.10	0.05	0.30	0.55
41	0.10	0.05	0.35	0.50
42	0.10	0.05	0.40	0.45
43	0.10	0.10	0.30	0.50
44	0.10	0.10	0.35	0.45
45	0.10	0.15	0.30	0.45
46	0.10	0	0.25	0.65
47	0.10	0	0.35	0.55
48	0.10	0	0.45	0.45
49	0.10	0.10	0.25	0.55
50	0.10	0.10	0.35	0.45
51	0.10	0.10	0.45	0.35
52	0.10	0.20	0.25	0.45
53	0.10	0.20	0.35	0.35
54	0.10	0.20	0.45	0.25
55	0.10	0	0.15	0.75
56	0.10	0	0.55	0.35
57	0.10	0.10	0.15	0.65
58	0.10	0.10	0.55	0.25
59	0.10	0.20	0.15	0.55
60	0.10	0.20	0.55	0.15
61	0.10	0.30	0.15	0.45
62	0.10	0.30	0.55	0.05
63	0.10	0	0.65	0.25

Table 9. Precedence Mix for Experiment 2 (Continued)

Model	Flash	Immediate	Priority	Routine
64	0.10	0.10	0.65	0.15
65	0.10	0.20	0.65	0.05
66	0.10	0.10	0.75	0.05
67	0.10	0.90	0	0
68	0.10	0.80	0.10	0
69	0.20	0	0.15	0.65
70	0.20	0	0.55	0.25
71	0.20	0.10	0.15	0.55
72	0.20	0.10	0.55	0.15
73	0.20	0.20	0.15	0.45
74	0.20	0.20	0.55	0.05
75	0.20	0.30	0.15	0.35
76	0.20	0.30	0.50	0
77	0.20	0	0.65	0.15
78	0.20	0.10	0.65	0.05
79	0.20	0.80	0	0
80	0.30	0.40	0	0.30
81	0.30	0.40	0.20	0.10
82	0.30	0.40	0.10	0.20
83	0.30	0.50	0	0.20
84	0.30	0.50	0.10	0.10
85	0.30	0.60	0	0.10
86	0.30	0.70	0	0
87	0.40	0.40	0	0.20
88	0.40	0.40	0.10	0.10
89	0.40	0.50	0	0.10
90	0.40	0.60	0	0
91	0.50	0.40	0.10	0
92	0.50	0.50	0	0
93	0.50	0.10	0.10	0.30
94	0.50	0.30	0.10	0.10
95	0.60	0.40	0	0
96	0.60	0.10	0.10	0.20
97	0.60	0.20	0.10	0.10
98	0.70	0.30	0	0
99	0.70	0.10	0.10	0.10
100	0.70	0.20	0	0.10
101	0.80	0.20	0	0
102	0.80	0.10	0	0.10
103	0.90	0.10	0	0

Table 10. Parameters for Experiment 4

Plot Number*	r	C	Precedence Mix F	I	P	R
1	1	0.2	.05	.05	.35	.55
2	1	0.2	.10	.10	.35	.45
3	1	0.2	.10	.10	.45	.35
4	1	0.2	.10	.20	.45	.25
5	1	0.2	.10	.10	.15	.65
6	1	0.2	.10	.20	.55	.15
7	1	0.2	.20	.30	.50	0
8	1	0.2	.10	.20	.65	.05
9	1	0.2	.25	.25	.25	.25
10	1	0.4	.25	.25	.25	.25
11	2	0.3	.25	.25	.25	.25
12	4	0.2	.25	.25	.25	.25
13	4	0.3	.25	.25	.25	.25
14	5	0.4	.25	.25	.25	.25
15	10	0.2	.25	.25	.25	.25
16	10	0.4	.25	.25	.25	.25

*Reference the plot of the observed data (Appendix C).

Table 11. Mean Transit Times in Seconds for Test 11

Model	Flash	Immediate	Priority	Routine
1	0	0	1885	2404
2	0	0	1730	2240
3	0	0	2407	2950
4	0	2000	2057	2481
5	0	2055	2363	2630
6	0	1855	2310	2631
7	1780	2017	2239	2797
8	1681	0	1862	2391
9	1618	0	2168	2839
10	1793	0	0	2685
11	1790	2223	2621	0
12	1620	2303	0	0
13	1877*	2598	0	0
14	0	0	0	2268
15	2012*	0	0	0

Table 12. Mean Transit Times in Seconds for Test 12

Model	Flash	Immediate	Priority	Routine
1	0	0	2502	18710
2	0	0	2195	9680
3	0	0	3930	24853*
4	0	2218	2951	14126
5	0	2518	4485	17562
6	0	2466	4406	11875
7	1704	2292	2860	6762
8	1503	0	2077	3837
9	1644	0	2670	4886
10	1707	0	0	5880
11	1689	2405	3981	0
12	1808*	3007*	0	0
13	1763	2329	0	0
14	0	0	0	6849
15	2012*	0	0	0

*Exceeds criteria specified in Table 3.

Table 13. Mean Transit Times in Seconds for Test 13

Model	Flash	Immediate	Priority	Routine
1	0	0	3782	50472*
2	0	0	2357	23936*
3	0	0	7294	15154
4	0	2440	3272	30306*
5	0	2906*	14867*	8396
6	0	2301	7443	44793*
7	1577	2538	3771	11739
8	1637	0	2587	9642
9	1542	0	3791	22141*
10	1635	0	0	8852
11	1773	2920*	4352	0
12	1836*	9773*	0	0
13	1848*	3491*	0	0
14	0	0	0	23740*
15	2012*	0	0	0

Table 14. Mean Transit Times is Seconds for Test 21

Model	Flash	Immediate	Priority	Routine
1	0	0	2114	2821
2	0	0	1816	2249
3	0	0	2093	2829
4	0	1927	2158	2649
5	0	1970	2499	2703
6	0	1835	2085	2892
7	1584	1995	1742	2305
8	1620	0	2015	2517
9	1558	0	1826	2124
10	1720	0	0	2134
11	1669	1670	2033	0
12	1735	2317	0	0
13	1670	2216	0	0
14	0	0	0	2101
15	1958*	0	0	0

*Exceeds criteria specified in Table 3.

Table 15. Mean Transit Times in Seconds for Test 22

Model	Flash	Immediate	Priority	Routine
1	0	0	2450	10507
2	0	0	2107	14306
3	0	0	2405	7671
4	0	2013	2297	6269
5	0	2304	4213	6685
6	0	1960	3624	13212
7	1662	2440	2876	4329
8	1798	0	2019	4462
9	1627	0	2208	4578
10	1654	0	0	4779
11	1743	2307	3165	0
12	1626	2182	0	0
13	1739	2491	0	0
14	0	0	0	13143
15	1958*	0	0	0

Table 16. Mean Transit Times in Seconds for Test 23

Model	Flash	Immediate	Priority	Routine
1	0	0	2726	20397
2	0	0	2437	32469*
3	0	0	4644	22651*
4	0	2623	5893	39407*
5	0	3244*	6644	31126*
6	0	2505	6040	50026*
7	1659	2645	5655	43172*
8	1538	0	2289	8883
9	1650	0	2905	10787
10	1704	0	0	9988
11	1670	2231	3012	0
12	1616	4222*	0	0
13	1714	2400	0	0
14	0	0	0	27319*
15	1958*	0	0	0

*Exceeds criteria specified in Table 3.

Table 17. Mean Transit Times in Seconds for Test 31

Model	Flash	Immediate	Priority	Routine
1	0	0	2108	2734
2	0	0	1945	2336
3	0	0	1964	2368
4	0	1826	2006	2862
5	0	1821	2024	2365
6	0	1787	1901	1980
7	1589	1906	2300	3440
8	1568	0	1788	2167
9	1657	0	2053	3473
10	1636	0	0	2274
11	1618	2023	2352	0
12	1583	1995	0	0
13	1642	1581	0	0
14	0	0	0	1977
15	1709	0	0	0

Table 18. Mean Transit Times in Seconds for Test 32

Model	Flash	Immediate	Priority	Routine
1	0	0	2331	4001
2	0	0	2103	9927
3	0	0	2949	35058*
4	0	2558	2942	13928
5	0	2179	3638	8985
6	0	2151	4566	18905
7	1689	2206	2430	3154
8	1666	0	2070	4300
9	1623	0	2399	3688
10	1443	0	0	3937
11	1716	2255	2412	0
12	1591	2919*	0	0
13	1625	2144	0	0
14	0	0	0	3580
15	1709	0	0	0

*Exceeds criteria specified in Table 13.

Table 19. Mean Transit Times in Seconds for Test 33

Model	Flash	Immediate	Priority	Routine
1	0	0	2755	47182*
2	0	0	2459	53372*
3	0	0	10415	0
4	0	2445	3954	51794*
5	0	3072*	22486*	4728
6	0	2424	13025	9241
7	1524	2852*	6479	38262*
8	1493	0	2376	14993
9	1674	0	3732	29073*
10	1590	0	0	23362*
11	1581	2297	3454	0
12	1512	3004*	0	0
13	1731	2587	0	0
14	0	0	0	23700*
15	1709	0	0	0

Table 20. Mean Transit Times in Seconds for Test 41

Model	Flash	Immediate	Priority	Routine
1	0	0	1857	2269
2	0	0	1670	2012
3	0	0	1883	2822
4	0	1917	2216	2466
5	0	1837	2084	2773
6	0	1842	2268	3452
7	1622	2000	2540	2698
8	1678	0	1704	2082
9	1612	0	1787	2498
10	1551	0	0	2016
11	1669	1759	1999	0
12	1619	1883	0	0
13	1662	2227	0	0
14	0	0	0	1845
15	1749	0	0	0

*Exceeds criteria specified in Table 3.

Table 21. Mean Transit Times in Seconds for Test 42

Model	Flash	Immediate	Priority	Routine
1	0	0	2192	16418
2	0	0	2278	14452
3	0	0	2636	14594
4	0	2323	2651	16260
5	0	2512	4434	42970*
6	0	1996	3264	26524*
7	1500	1767	1858	3085
8	1552	0	2080	3560
9	1553	0	1998	3558
10	1709	0	0	7412
11	1606	2056	2386	0
12	1600	2397	0	0
13	1638	3138*	0	0
14	0	0	0	10083
15	1749	0	0	0

Table 22. Mean Transit Times in Seconds for Test 43

Model	Flash	Immediate	Priority	Routine
1	0	0	2482	19983
2	0	0	1939	25172*
3	0	0	12668	0
4	0	2373	3365	38504*
5	0	2733*	7693	46387*
6	0	2370	15643*	0
7	1640	2263	3140	10015
8	1698	0	2391	10038
9	1644	0	2395	7681
10	1615	0	0	16045
11	1676	2582	3685	0
12	1547	3973*	0	0
13	1593	2629	0	0
14	0	0	0	22321*
15	1749	0	0	0

*Exceeds criteria specified in Table 3.

Table 23. Mean Transit Times in Seconds for Test 51

Model	Flash	Immediate	Priority	Routine
1	0	0	1776	2191
2	0	0	1550	2005
3	0	0	1752	2099
4	0	1751	2033	2328
5	0	1921	2562	3950
6	0	1874	2173	2729
7	1560	1763	1905	2024
8	1542	0	1801	1969
9	1539	0	1846	2017
10	1590	0	0	1939
11	1597	1958	2204	0
12	1623	1976	0	0
13	1641	2378	0	0
14	0	0	0	2765
15	1765	0	0	0

Table 24. Mean Transit Times in Seconds for Test 52

Model	Flash	Immediate	Priority	Routine
1	0	0	2270	5240
2	0	0	2044	13361
3	0	0	2647	17507
4	0	1944	2295	6212
5	0	2558	6015	14606
6	0	2074	3265	7806
7	1690	2047	2432	3032
8	1607	0	2395	4715
9	1635	0	2105	3769
10	1462	0	0	3144
11	1578	1985	2219	0
12	1550	2142	0	0
13	1612	2066	0	0
14	0	0	0	7561
15	1765	0	0	0

Table 25. Mean Transit Times in Seconds for Test 53

Model	Flash	Immediate	Priority	Routine
1	0	0	2849	44932*
2	0	0	2277	26932*
3	0	0	3667	50262*
4	0	2427	4260	47125*
5	0	3463*	34853*	0
6	0	2215	5872	20667
7	1514	2423	5169	19432
8	1514	0	2324	14694
9	1584	0	3047	14021
10	1574	0	0	4194
11	1550	2161	2893	0
12	1614	3280*	0	0
13	1593	2145	0	0
14	0	0	0	19579
15	1765	0	0	0

Table 26. Mean Values of the Mean Transit Times for each Test and Trial in Experiment 1

r	C	Flash	Immediate	Priority	Routine
1	0.2	1771	2150	2164	2574
1	0.3	1729	2462	3206	11365
1	0.4	1733	3767	5352	22652
2	0.2	1689	1990	2038	2484
2	0.3	1726	2242	2736	8176
2	0.4	1689	2839	4225	26930
4	0.2	1625	1848	2044	2543
4	0.3	1633	2345	2784	9951
4	0.4	1602	2672	7114	29571
5	0.2	1645	1923	2001	2448
5	0.3	1613	2313	2578	14447
5	0.4	1645	2703	5540	21794
10	0.2	1607	1946	1960	2365
10	0.3	1612	2117	2769	7905
10	0.4	1589	2588	6721	26184

*Exceeds criteria specified in Table 3.

Table 27. Mean Values of the Mean Transit Times for each Test in Experiment 1

r	Flash	Immediate	Priority	Routine
1	1744	2793	3574	12197
2	1701	2357	3000	12863
4	1620	2288	3981	14022
5	1634	2313	3373	12896
10	1603	2214	3817	12151

Table 28. Mean Waiting Times in Queue 5 in Experiment 1

r	C	Mean Waiting Time
1	0.2	1548
1	0.3	12106
1	0.4	38610
2	0.2	1581
2	0.3	9008
2	0.4	33183
4	0.2	1840
4	0.3	11853
4	0.4	48427
5	0.2	1415
5	0.3	13548
5	0.4	33936
10	0.2	1539
10	0.3	8724
10	0.4	34037

Table 29. Excessive Transit Times in Minutes in Experiment 2 when C = 0.2

Model Number	Precedence	PRECEDENCE MIX F	I	P	R	Mean Transit Time	Percentage Utilization of Fac. 5
101	Flash	.80	.20	0	0	30.30	31.0
102	Flash	.80	.10	0	.10	32.43	34.7
103	Flash	.90	.10	0	0	32.11	30.4

Table 30. Excessive Transit Times in Minutes in Experiment 2 when C = 0.3

Model Number	Precedence	PRECEDENCE MIX F	I	P	R	Mean Transit Time	Percentage Utilization of Fac. 5
3	Routine	0	.10	.35	.55	487.71	100
4	Routine	0	.15	.40	.45	419.73	100
5	Routine	0	.15	.35	.50	499.08	100
6	Routine	0	.15	.30	.55	416.00	100
12	Routine	0	.20	.25	.55	365.25	100
23	Routine	0	0	.65	.35	457.88	100
37	Routine	.05	.10	.40	.45	389.94	100
66	Routine	.10	.10	.75	.05	686.07	96.2
68	Immediate	.10	.80	.10	0	58.49	97.1
79	Immediate	.20	.80	0	0	73.94	87.6
82	Immediate	.30	.40	.10	.20	48.19	75.5
83	Immediate	.30	.50	0	.20	61.96	98.7
85	Immediate	.30	.60	0	.10	48.66	90.2
86	Immediate	.30	.70	0	0	57.73	76.0
90	Immediate	.40	.60	0	0	62.64	74.7
91	Immediate	.50	.40	.10	0	50.28	70.2
92	Immediate	.50	.50	0	0	48.05	68.2
95	Immediate	.60	.40	0	0	47.80	68.8
98	Immediate	.70	.30	0	0	48.08	48.6
101	Immediate	.80	.20	0	0	53.14	48.6
103	Flash	.90	.10	0	0	30.32	32.2

Table 31. Excessive Transit Times in Minutes in Experiment 2 when C = 0.4

Model Number	Precedence	PRECEDENCE MIX F	I	P	R	Mean Transit Time	Percentage Utilization of Fac. 5
1	Routine	0	.05	.40	.55	463.66	100
2	Routine	0	.10	.40	.50	603.39	100
3	Routine	0	.10	.35	.55	580.71	100
4	Routine	0	.15	.40	.45	720.76	100
5	Routine	0	.15	.35	.50	604.21	100
6	Routine	0	.15	.30	.55	726.61	100
7	Routine	0	0	.25	.75	528.86	100
8	Routine	0	0	.35	.65	589.07	100
9	Routine	0	0	.45	.55	694.55	100
10	Routine	0	.10	.25	.65	644.79	100
11	Routine	0	.10	.45	.45	446.51	100
12	Routine	0	.20	.25	.55	390.51	100
13	Routine	0	.20	.35	.45	582.69	100
14	Routine	0	.20	.45	.35	532.35	100
15	Routine	0	0	.15	.85	661.73	100
17	Routine	0	0	.15	.75	401.82	100
19	Routine	0	.20	.15	.65	566.09	100
20	Priority	0	.20	.55	.25	451.59	100
21	Routine	0	.30	.15	.55	514.17	100
22	Priority	0	.30	.55	.15	304.04	100
23	Routine	0	0	.65	.35	663.57	100
24	Priority	0	.10	.65	.25	278.02	100
25	Priority	0	.20	.65	.15	317.99	100
26	Priority	0	.30	.65	.05	360.49	100
28	Priority	0	.10	.75	.15	526.76	100
29	Priority	0	.20	.75	.15	518.13	100
30	Priority	0	0	.85	.15	421.95	100
31	Priority	0	.10	.85	.05	452.86	100
32	Priority	0	0	.95	.05	511.71	100
33	Routine	.05	.05	.40	.50	588.05	100
34	Routine	.05	.05	.35	.55	437.52	100
36	Routine	.05	.10	.35	.50	646.28	100
37	Routine	.05	.10	.40	.45	545.35	100
38	Routine	.05	.15	.30	.50	517.81	100
39	Routine	.05	.15	.35	.45	696.16	100
40	Routine	.10	.05	.30	.55	506.12	100
41	Routine	.10	.05	.35	.50	809.16	100
42	Routine	.10	.05	.40	.45	514.02	100
43	Routine	.10	.10	.30	.50	601.46	100
45	Routine	.10	.15	.30	.45	533.61	99.5
47	Routine	.10	0	.45	.45	785.35	100

Table 31. Excessive Transit Times in Minutes in Experiment 2 when C = 0.4 (Continued)

Model Number	Precedence	PRECEDENCE MIX F	I	P	R	Mean Transit Time	Percentage Utilization of Fac. 5
48	Routine	.10	0	.45	.45	797.03	100
49	Routine	.10	.10	.25	.55	659.95	100
53	Routine	.10	.20	.35	.35	552.84	100
56	Routine	.10	0	.55	.35	590.73	100
57	Routine	.10	.10	.15	.65	416.85	100
59	Routine	.10	.20	.15	.55	668.15	100
60	Priority	.10	.20	.55	.15	486.70	100
61	Routine	.10	.30	.15	.45	527.54	100
62	Priority	.10	.30	.55	.05	458.93	100
65	Priority	.10	.20	.65	.05	444.69	100
66	Priority	.10	.10	.75	.05	464.03	100
67	Immediate	.10	.90	0	0	544.63	100
68	Immediate	.10	.80	.10	0	377.28	100
70	Routine	.20	0	.55	.25	663.82	100
72	Routine	.20	.10	.55	.15	425.05	100
76	Priority	.20	.30	.50	0	308.19	100
78	Priority	.20	.10	.65	.05	225.29	100
79	Immediate	.20	.80	0	0	413.39	100
80	Immediate	.30	.40	0	.30	52.37	100
81	Immediate	.30	.40	.20	.10	52.60	93.4
82	Immediate	.30	.40	.10	.20	49.82	100
83	Immediate	.30	.50	0	.20	68.50	100
84	Immediate	.30	.50	.10	.10	66.78	100
85	Immediate	.30	.60	0	.10	71.68	100
86	Immediate	.30	.70	0	0	240.59	100
87	Immediate	.40	.40	0	.20	46.28	88.0
88	Immediate	.40	.40	.10	.10	47.23	79.7
89	Routine	.40	.50	0	.10	75.17	100
90	Immediate	.40	.60	0	0	235.26	100
91	Immediate	.50	.40	.10	0	49.87	81.3
92	Immediate	.50	.50	0	0	88.48	94.3
94	Immediate	.50	.30	.10	.10	58.04	89.9
95	Immediate	.60	.40	0	0	56.17	69.6
97	Immediate	.60	.20	.10	.10	45.29	71.1
98	Immediate	.70	.30	0	0	71.30	64.1
101	Immediate	.80	.20	0	0	47.97	43.7
102	Flash	.80	.10	0	.10	30.82	46.3
103	Flash	.90	.10	0	0	31.95	32.6

Table 32. Values of Weibull Distribution Parameters in Experiment 4

Plot Number*	$\hat{\gamma}$	$\hat{\alpha}_i$	$\hat{\beta}_i$	Range
		4.523	1.37	$0 \le t_1 \le 45$
1	4.83	2.14	0.80	$45 \le t_2 \le \infty$
		4.055	1.38	$0 \le \hat{t}_1 \le 25$
2	4.83	2.7	1.15	$25 \le \hat{t}_2 \le \infty$
3	4.85	4.523	1.37	$0 \le \hat{t} \le \infty$
		4.523	1.37	$0 \le \hat{t}_1 \le 50$
4	4.78	2.14	0.80	$50 \le \hat{t}_2 \le \infty$
		4.055	1.38	$0 \le \hat{t}_1 \le 30$
		2.719	1.00	$30 \le \hat{t}_2 \le 75$
5	4.81	1.284	0.60	$75 \le \hat{t}_3 \le \infty$
		4.523	1.37	$0 \le \hat{t}_1 \le 40$
6	4.75	2.14	0.80	$40 \le t_2 \le \infty$
		4.523	1.37	$0 \le \hat{t}_1 \le 65$
7	4.83	2.14	0.80	$65 \le \hat{t}_2 \le \infty$
		4.523	1.37	$0 \le \hat{t}_1 \le 60$
8	4.68	2.14	0.80	$60 \le \hat{t}_2 \le \infty$
		3.67	1.30	$0 \le \hat{t}_1 \le 42$
9	8.13	1.823	0.80	$42 \le \hat{t}_2 \le \infty$
		4.482	1.30	$0 \le \hat{t}_1 \le 33$
		2.719	0.80	$33 \le \hat{t}_2 \le 116$
10	8.10	2.225	0.60	$116 \le \hat{t}_3 \le \infty$

Table 32. Values of Weibull Distribution Parameters in Experiment 4 (Continued)

Plot Number*	$\hat{\gamma}$	$\hat{\alpha}_i$	$\hat{\beta}_i$	Range
		3.005	1.10	$0 \leq \hat{t}_1 \leq 50$
11	8.13	1.283	0.60	$50 \leq \hat{t}_2 \leq \infty$
12	8.13	2.72	1.20	$0 \leq \hat{t} \leq \infty$
13	8.14	3.005	1.10	$0 \leq \hat{t} \leq \infty$
		4.005	1.15	$0 \leq \hat{t}_1 \leq 16$
		2.72	0.95	$16 \leq \hat{t}_2 \leq 58$
14	8.13	1.221	0.42	$58 \leq \hat{t}_3 \leq \infty$
15	8.14	2.72	1.20	$0 \leq \hat{t} \leq \infty$
		4.055	1.15	$0 \leq \hat{t}_1 \leq 41$
		2.72	0.95	$41 \leq \hat{t}_2 \leq 164$
16	8.14	1.221	0.42	$164 \leq \hat{t}_3 \leq \infty$

*References the plot from which α_i and β_i were estimated in Appendix C.

Table 33. Two Classified Tape Facilities (5 and 9) in Experiment 5 when C = 0.3

Queue or Facility Number	E(t) = 240 sec Facility Utilization	Waiting Time	E(t) = 180 sec Facility Utilization	Waiting Time	E(t) = 120 sec Facility Utilization	Waiting Time
1	.2321	8	.2939	15	.4710	39
2	.7472	474	.8425	758	.9970	3435
3	.7915	585	.8671	1122	1.000	3917
4	.5267	546	.7211	1128	1.000	3178
5	.8291	1721	.8863	7681	1.000	22066
6	.5645	467	.6813	634	1.000	6817
7	.4747	395	.4529	332	.7754	1312
8	.4529	353	.5612	557	.8558	1570
9	.6223	1410	.7802	9633	1.000	21986

Table 34. Two Classified Tape Facilities (5 and 9) in Experiment 5 when C = 0.6

Queue or Facility Number	E(t) = 360 sec Facility Utilization	Waiting Time	E(t) = 300 sec Facility Utilization	Waiting Time	E(t) = 240 sec Facility Utilization	Waiting Time
1	.1601	4	.1700	4	.2303	10
2	.4970	130	.5201	162	.6855	369
3	.4580	163	.4761	214	.5939	318
4	.0533	36	.1431	145	.1889	215
5	.9390	3919	.9649	12035	1.000	43170
6	.3330	220	.3609	214	.4479	362
7	.3005	206	.2997	191	.3589	162
8	.3191	222	.3265	157	.4101	258
9	.8472	3913	.9447	13343	1.000	41010

Table 35. Two Classified Tape Facilities (5 and 9) in Experiment 5 when C = 0.9

Queue or Facility Number	E(t) = 360 sec	
	Facility Utilization	Waiting Time
1	.1569	6
2	.4728	121
3	.1661	67
4	.0024	0
5	1.000	67104
6	.3215	135
7	.2164	111
8	.2285	103
9	1.000	64746

Table 36. Three Classified Tape Facilities (5, 9 and 10) in Experiment 5 when C = 0.3

Queue or Facility Number	E(t) = 240 sec		E(t) = 180 sec		E(t) = 120 sec	
	Facility Utilization	Waiting Time	Facility Utilization	Waiting Time	Facility Utilization	Waiting Time
1	.2134	9	.3231	16	.4593	5
2	.7033	458	.9131	934	.9870	1783
3	.7848	607	.9318	2331	1.000	3554
4	.5587	543	.8620	2197	.9951	2831
5	.7313	902	.8829	1608	.9786	4209
6	.5174	468	.7288	792	1.000	14471
7	.3987	227	.5028	330	.8223	1665
8	.4421	322	.5369	424	.9203	2777
9	.4505	574	.6788	1098	.9350	3163
10	.0468	235	.3522	786	.7402	2431

Table 37. Three Classified Tape Facilities (5, 9 and 10) in Experiment 5 when C = 0.6

Queue or Facility Number	E(t) = 240 sec		E(t) = 180 sec		E(t) = 120 sec*	
	Facility Utilization	Waiting Time	Facility Utilization	Waiting Time	Facility Utilization	Waiting Time
1	.2429	11	.3370	17		
2	.7046	298	.8879	815	1.000	
3	.5943	269	.7126	407	1.000	
4	.2409	235	.3944	286		
5	.9960	6572	.9719	15285	1.000	
6	.6150	644	.7304	1299	1.000	
7	.3857	268	.5249	533		
8	.4119	349	.5322	374		
9	.9628	4097	.9736	16839	1.000	
10	.9077	3929	.9381	14965	1.000	

Table 38. Three Classified Tape Facilities (5, 9 and 10) in Experiment 5 when C = 0.9

Queue or Facility Number	E(t) = 360 sec		E(t) = 300 sec	
	Facility Utilization	Waiting Time	Facility Utilization	Waiting Time
1	.1460	5	.1880	6
2	.4593	128	.5509	158
3	.1999	128	.1923	44
4	.0053	0	.0081	0
5	.9046	2460	1.000	35033
6	.3222	202	.3676	196
7	.2692	118	.3233	153
8	.2933	145	.3283	172
9	.8152	1782	1.000	35647
10	.5754	1747	1.000	34636

*At this point the system becomes so saturated that GPSS III Error Condition Number 68A is received. This is an indication that storage capacity has been exceeded. Statistics are printed but they are not significant.

Table 39. Four Classified Tape Facilities (5, 9, 10 and 11) in Experiment 5 when C = 0.3

Queue or Facility Number	E(t) = 240 sec		E(t) = 180 sec		E(t) = 120 sec*	
	Facility Utilization	Waiting Time	Facility Utilization	Waiting Time	Facility Utilization	Waiting Time
1	.2134	9	.2973	13		
2	.7033	458	.8482	602		
3	.7848	607	.9164	1674	1.000	
4	.5587	543	.8121	1602		
5	.7313	902	.8627	1685		
6	.5174	468	.7512	896	1.000	
7	.3987	227	.5595	585		
8	.4421	322	.5167	338		
9	.4505	574	.6320	862		
10	.0468	235	.3278	607		
11	0	0	.0615	1122		

Table 40. Four Classified Tape Facilities (5, 9, 10 and 11) in Experiment 5 when C = 0.6

Queue or Facility Number	E(t) = 240 sec		E(t) = 180 sec		E(t) = 120 sec*	
	Facility Utilization	Waiting Time	Facility Utilization	Waiting Time	Facility Utilization	Waiting Time
1	.2181	8	.3283	22		
2	.7057	501	.8689	760		
3	.6211	284	.6829	337	1.000	
4	.1817	111	.3486	304		
5	.9242	2378	.9838	4732		
6	.5541	609	.8012	989	1.000	
7	.4060	334	.5558	476		
8	.3964	227	.5721	478		
9	.8499	1468	.9773	3628		
10	.5832	1322	.9513	3215		
11	.2748	1585	.8348	2634		

*See Footnote Table 37.

Table 41. Four Classified Tape Facilities (5, 9, 10 and 11) in Experiment 5 when C = 0.9

Queue or Facility Number	E(t) = 300 sec Facility Utilization	E(t) = 300 sec Waiting Time	E(t) = 240 sec Facility Utilization	E(t) = 240 sec Waiting Time	E(t) = 180 sec Facility Utilization	E(t) = 180 sec Waiting Time
1	.1892	6	.2343	9	.3219	21
2	.5939	287	.7106	459	.8827	737
3	.1977	82	.2398	90	.3732	146
4	.0025	0	.0048	0	.0134	0
5	.9371	4083	.9802	12287	1.000	45313
6	.4536	427	.5324	511	.6516	546
7	.3692	234	.3874	216	.4571	357
8	.3487	245	.4307	244	.4689	285
9	.9052	3295	.9979	12902	1.000	46101
10	.8075	2165	.9423	11910	1.000	40864
11	.6033	1932	.8797	12434	1.000	46782

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